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SNAP-8 DIVISION

SNAP-8 MATERIALS REPORT FOR JANUARY-JUNE 1964

VOL. I - ELECTRICAL INSULATION DEVELOPMENT

BY R. P. DILLINGHAM

CONTRACT NAS 5-417

A REPORT TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER

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A Report To

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
SNAP-8 PROJECT OFFICE
H. O. SLONE, SNAP-8 PROJECT MANAGER

Report No. 2880 July 1964

AEROJET-GENERAL CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

FOREWORD

Aerojet-General Corporation is proceeding with the design and development of the SNAP-8 Power Conversion System, as authorized by National Aeronautics and Space Administration (NASA) Contract No. NAS 5-417.

The ultimate objective of the SNAP-8 Program is to design and develop a 35-kw electrical generating system for use in various space missions. The power source will be a nuclear reactor furnished by the Atomic Energy Commission (AEC). The SNAP-8 system will use a eutectic mixture of sodium and potassium (NaK) as the reactor coolant and will operate on a Rankine cycle, with mercury as the working fluid for the turbogenerator. It is to be launchable from a ground base and be capable of unattended full-power operation for a minimum of 10,000 hours. After the system is placed into orbit, it is to be capable of activation and shutdown by ground command.

This is the first of two volumes comprising the semiannual materials report submitted in partial fulfillment of the contract. Volume II covers the development of component materials.

The program was under the direction of R. S. Carey, Materials Department Manager, SNAP-8 Division, Von Karman Center. The following engineers contributed to the work reported in this volume: H. Bleil, F. Cassidy, R. P. Dillingham, and W. A. Hewgley.

The suggestions and guidance of P. L. Stone and J. P. Merutka, SNAP-8 Project Office, Lewis Research Center, NASA, are gratefully acknowledged.

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GLOSSARY

Abbreviations commonly used in the SNAP-8 Program are defined below.

AA	Alternator assembly
AEC	Atomic Energy Commission
AGC	Aerojet-General Corporation
AGN	Aerojet-General Nucleonics
AI	Atomics International
AOC	Award of contract
ATL	Acceptance test loop
AZFO	NASA - Azusa Field Office
BOD	Beneficial occupancy date
CGEST	Cold-gas electrical system test
CL	Corrosion loop (AGN)
CPC	Ceramic potting compounds
CTL	Component test loop (AGN)
DDAS	Digital data acquisition system
DWG	Drawing
EDM	Electrical-discharge machining
EFF	Efficiency
EGS	Electrical generating system
EM	Electromagnetic
EME	Electromagnetic equivalent
FPS	Flight prototype system
FPTF	Flight prototype test facility
FRA	Flight radiator assembly
GE	General Electric Company
GN_2S	Gaseous nitrogen stand
GPS	Ground prototype system
GPTF	Ground prototype test facility
HML	Heavy coating of ML (q.v.)
HR	Heat rejection
HRF	Heat rejection fluid
HRL	Heat rejection loop
HRS	Heat rejection system
HTL	Heat-transfer loop
L/C	Lubricant/coolant
L/CL	Lubricant/coolant loop
LeRC	Lewis Research Center
LML	Liquid mercury loop
LMS	Liquid mercury stand
LNL	Liquid NaK loop
LOL	Liquid organic loop
LOS	Liquid organic stand
LPL	Low power loop
MIS	Mercury injection system
Mix-4P3E Mix-5P4E	Polyphenyl ethers considered as lubricant/coolant fluids for the PCS*
ML	Pyre-ML, Du Pont polyimide organic resin; as employed in statorette serial numbers, indicates the use of this substance
MLA	Mercury loop assembly
MN_2S	Mercury-nitrogen system
MPMA	Mercury pump motor assembly
NaK	Eutectic mixture of sodium and potassium
NASA	National Aeronautics and Space Administration

*Mix-4P3E is bis(mix-phenoxyphenyl) ether, a mixture of the six possible isomers of bis(phenoxyphenyl) ether. Mix-5P4E is mix-bis(mix-phenoxyphenoxy)benzene, a mixture of the 18 possible isomers of bis(phenoxyphenoxy)benzene.

GLOSSARY (cont.)

NF	Nuclear facility
NHRA	NaK heat-rejection assembly
NPA	NaK pump assembly
NPMA	NaK pump motor assembly
NPS	Nuclear power system
NPSH	Net positive suction head
NS	Nuclear system
NSL	NaK simulation loop
ORNL	Oak Ridge National Laboratory
PBRF	Plum Brook Reactor Facility
PCS-1	Power Conversion System No. 1
PCS-2	Power Conversion System No. 2
PCS-3	Power Conversion System No. 3
PCS-4	Power Conversion System No. 4
PF	Power factor
PL	Primary loop
PLR	Parasitic load resistor
PMA	Pump motor assembly
PNLA	Primary NaK loop assembly
PO	Purchase order
PTAT	Preliminary type-approval test
PVT	Pressure-volume-temperature
R_B	Rockwell B (hardness)
RPL	Rated power loop
SC	Speed control
S8DS	SNAP-8 development system
S8ER	SNAP-8 experimental reactor
SL-1	System Loop Test Facility No. 1
SL-2	System Loop Test Facility No. 2
SL-3	System Loop Test Facility No. 3
SL-4	System Loop Test Facility No. 4
SMU	Structural mockup
SNAP	Systems for Nuclear Auxiliary Power
SR	Saturable reactor
SS	Stainless steel
TA	Turbine assembly
TAA	Turbine-alternator assembly
TAT	Type-approval test
TCL	Thermal convection loop (AGN)
TR	Transformer-reactor (assembly)
TS	Test section
TRW	Thompson Ramo Wooldridge
TSE	Test support equipment
VLB	Vehicle load breaker
VR	Voltage regulator-exciter
W/O	Without
WOO	Western Operations Office
-X, -1, -2, -3	Standing alone (i.e., not preceded by letters of the alphabet), these designations indicate design stages of SNAP-8 hardware

SNAP-8 MATERIALS REPORT FOR JANUARY-JUNE 1964
VOL. I - ELECTRICAL INSULATION DEVELOPMENT

by R. P. Dillingham

Aerojet-General Corporation

SUMMARY

1. An inorganic-insulated motor has been operated for 8000 hours at 450°F with steadily improving electrical values.

2. Screening tests have been run on 16 organic-encapsulant resins, resulting in the selection of six for the radiation-effects program and of three of those six for further trials in control-system components.

3. Life testing of organic-insulated statorettes was continued at 392°F, with no indication of failure with respect to insulation-resistance values.

4. NaK pump-motor-assembly (PMA) insulation development was finalized, and unit construction was continued.

5. Materials for the radiation-effects program were assembled, tested, and shipped to the reactor vendor for irradiation.

6. The Aerojet-designed terminals for the PMAs were received, tested, and accepted for construction.

7. A new type of monitoring method was devised and checked out for long-term temperature testing of ceramic terminals under vacuum conditions.

8. The compatibility of copper and mix-4P3E polyphenyl ether was studied, and it was tentatively concluded that the materials are compatible if no oxygen or oxygen source is present.

9. Development work was started with the aim of utilizing the organic resins selected by the screening program in strain-sensitive components of the controls system.

N66-14062

I. INTRODUCTION

The objectives of the SNAP-8 Electrical Insulation Development Program are (a) to select, test, and evaluate insulating materials and systems that are applicable to the various SNAP-8 electrical components; (b) to fabricate inorganic insulation systems for the heat-rejection-loop (HRL) and primary-loop NaK motors; and (c) to coordinate Aerojet-General subcontractor activities in the area of electrical insulation.

The emphasis during the first and second quarters of 1964 was on application of previously engineered systems to hardware units and on necessary modifications revealed by construction. Some long-term testing was continued, and some material screening for the radiation-effects program was completed.

The period was further characterized by completion of the first inorganic-insulated stator and the arrival and acceptance of Aerojet-designed terminal insulators for the pump-motor assemblies (PMAs).

In addition to the reported work, advice and laboratory aid were rendered in many areas not specifically covered by the insulation program, such as leak-detection methods for the turbine-alternator assembly, repair of the mercury-pump motor, and installation of rotor cans on the NaK PMA rotors.

Author

II. TEST RESULTS AND ANALYSIS

A. HIGH-TEMPERATURE MOTOR TEST

The testing of an inorganic-insulated motor to determine the long-term dielectric strength of the insulation system was continued. The motor stator was fabricated previously for the original two-loop SNAP-8 system, and the insulation system used in the stator is essentially the same as that now being employed in the new HRL and primary-loop NaK motors. This 1000-cps motor (Figure 1) has external bearings and operates on a reduced 60-cps voltage to eliminate the need for a special power supply.

The unit has operated satisfactorily for 8000 hours to date, with a winding hot-spot temperature of 450°F. As shown in Figure 2, the winding insulation resistance has not changed significantly through 8000 hours of aging at 450°F. These results indicate that the inorganic insulation system is stable and is therefore promising for long-term operation at 450°F - a level anticipated for the new NaK motors.

The test temperature has been ranging from 427 to 450°F because it is not controlled by a heat source other than the motor itself, but is dependent on the heat losses through the insulation layer surrounding the unit.

B. EVALUATION OF ORGANIC RESINS

Efforts were continued with the aim of determining the most promising organic resins to use in impregnating and encapsulating the alternator electronic-control components. Fifteen resins had previously been selected for evaluation. One of these was eliminated from further consideration during this report period, because of undesirable handling characteristics. Two additional resins selected by General Electric Company (GE) for use in the SNAP-8 alternator and voltage regulator-exciter were included in the program, bringing to 16 the total number undergoing screening.

A weight-loss test was selected for initial screening of the 16 resins. This test, which is based on MIL-I-16923D specifications, provides indications of the thermal stability of resins. Samples of the various resins were cast in glass petri dishes about 2 in. in diameter and 1/2 in. in height. Following curing in accordance with recommendations made by the resin manufacturer, the samples were removed from the dishes. The samples were then

1. Dried at 220°F in air for 24 hours to remove moisture and low-temperature volatiles
2. Cooled to room temperature in a desiccator and weighed to the nearest 0.1 mg on an analytical balance
3. Thermally aged for 168 hours at 392°F in a furnace with forced-air ventilation
4. Subjected again to Step 2.

Table 1 summarizes the weight-loss data obtained for the 16 resins following 168 hours at 392°F. Testing of the samples was resumed, but a furnace-control failure during the second 168-hour run destroyed the samples. Another test was then initiated with smaller samples that were cast at the same time as the original samples. Table 2 summarizes the weight-loss data for the second sample run up to 1196 hours.

C. ORGANIC-INSULATED STATORETTES

The testing of promising organic insulation systems applied in stator-core sections was continued. The procedure consists of exposing test units (statorettes) either to air or to organic fluids [polyphenyl ethers, mix-4P3E (Dow ET-378 used in this program) or mix-5P4E (Monsanto OS-124 in this program)] in a furnace at 392°F. Eight statorettes using four candidate organic insulation systems are undergoing evaluation. Four of the units were aged in air and serve as controls. Of the remaining four, two were immersed in mix-4P3E and two in mix-5P4E. Throughout the test, the statorette-winding insulation resistance (hereafter referred to as "IR") was measured to establish trends in the condition of the electrical insulation.

Table 3 provides a description of the insulation systems used in the eight statorettes. Tables 4 through 11 summarize the test results obtained to date. The most significant results and tentative conclusions reached thus far are summarized below.

1. Statorettes HML-1 and HML-2

Statorettes HML-1 and HML-2 have each accumulated 10,000 hours of aging at 392°F. Following 9709 hours at 392°F, the control unit (HML-2), operating in air, had an IR of 6.7×10^{11} ohms as compared with 8.9×10^{9} ohms for HML-1, which was immersed in mix-5P4E fluid. Because the corresponding IR values for these units following only 240 hours of aging at 392°F are approximately the same as for the 9709-hour aging point, it appears that the fluid is compatible with ML-polymer materials. It should be noted, however, that the resistivity of the fluid is less than that of air at 392°F, based on a comparison of IR values obtained for the two units. Any consideration of this material as a working fluid in contact with the electrical system should therefore include the fact that the system's IR will be lowered to a base value, but will not materially change for 10,000 hours at 392°F. These statorettes have been removed from the test furnace and stored. The values shown in Tables 4 and 5 were taken before the end of the 10,000-hour test.

2. Statorettes ML/997-1 and ML/997-2

Statorettes ML/997-1 and ML/997-2 have each accumulated 10,000 hours of aging at 392°F. The values shown in Tables 6 and 7 were taken before the end of the 10,000-hour test. Throughout the test, the control unit (ML/997-1), aged in air, has shown an IR of about 5.0×10^{11} ohms. The ML/997-2, a similar unit immersed in mix-5P4E fluid throughout the same period, exhibited an IR range of 2.2×10^{9} to 1.3×10^{10} ohms. This variation is attributed to changes in the level of mix-5P4E in the statorette container resulting from evaporation of the fluid. As an example, for complete immersion in the fluid, the IR was found to be about 10^{9} ohms. When a portion of the statorette winding was exposed to air following evaporation of some of the fluid, the IR increased to the 10^{10}-ohm level. On this basis, it appears that the insulating materials used in these statorettes are compatible with mix-5P4E; as was the case for HML-1, however, the winding IR is reduced significantly by mix-5P4E. These statorettes have also been removed and stored.

3. Statorettes ML-3 and ML-5

Statorettes ML-3 and ML-5 have each accumulated 4356 hours of aging at 392°F (Tables 8 and 10). The control unit (ML-5), aged in air, has maintained an IR between 7.0×10^{11} ohms and infinity (10^{12} ohms or more). The ML-3, a similar unit immersed in mix-4P3E fluid, exhibited an IR of 6.6×10^{7} ohms following 45 hours of aging. Then, as evaporation of mix-4P3E occurred, the winding IR increased. Following 2732 hours of aging, no fluid remained in the statorette container and the IR had increased to 9.0×10^{10} ohms. After 4356 hours, additional fluid originally absorbed in the winding apparently had evaporated, because the IR increased to 3.7×10^{11} ohms. These observations show that mix-4P3E reduces the IR of the insulation system; however, there is no evidence as yet that the fluid is chemically incompatible with the insulating materials used in the statorettes.

4. Statorettes ML-4 and ML-6

Statorettes ML-4 and ML-6 have each accumulated 4356 hours of aging at 392°F (Tables 9 and 11). The control statorette (ML-6), aged in air, has maintained a winding IR of from 1.7×10^{10} ohms to infinity (10^{12} ohms or more) throughout the test. The ML-4,a similar unit immersed in mix-4P3E fluid, showed an IR of 4.4×10^7 ohms after 45 hours of aging. Evaporation of the fluid occurred so rapidly that none remained in the test container after 2732 hours of aging. The winding IR at this point in the test had increased slightly to 3.2×10^8 ohms.

Inspection following 2732 hours of aging showed that mix-4P3E had chemically attacked the varnish (Westinghouse Doryl) that was used to impregnate the winding. Subsequent measurements through 4356 hours of aging revealed continuing improvement in IR values (maximum of 1.7×10^{10} ohms), although the varnish is apparently badly deteriorated. The latter finding suggests that visual and electrical measurements following 10,000 hours of aging at 392°F are required to establish the full extent of insulation-system degradation.

Electrical monitoring of the statorettes will continue until the units have accumulated 10,000 hours of aging at 392°F. Following 10,000 hours, all statorettes will be inspected and electrically tested to destruction to determine the final condition of the insulation.

D. HRL AND PRIMARY-LOOP NaK-MOTOR INSULATION DEVELOPMENT

Efforts were continued with the aim of improving the techniques used in handling, applying, and processing inorganic electrical-insulating materials used in the -1 HRL and primary-loop NaK motors. The techniques and procedures described below were developed and were incorporated in the winding procedure for the NaK motors (Ref. 1).

1. Aluminum rings were fabricated for use in supporting the ends of the stator-slot liner insulation during winding operations. These rings permit the end turns of the coil to be flexed without developing excessive mechanical forces on the slot liners, thus preventing damage to the liners.

2. Teflon inserts were constructed for use in supporting the sides of the slot liners that extend beyond the ends of the stator slots. These inserts protect the slot liners from bending forces encountered during installation of the coils in the stator core.

3. Mylar pressure-sensitive tape is used to tape the tops of the liners in the stator slots to the core; this prevents slot-liner shifting during coil installation.

4. Burrs are removed from the stator core-end laminations by manual filing of the lamination edges, followed by vapor honing of the edges with a ceramic slurry.

5. The first six coils (rather than four) placed in the slots are left with the opposite coil side open until completion of the remaining coil throws around the stator bore.

6. More Mylar wrapping is added to the first six coil sides for increased flexibility at this pivot point, in accordance with Step 1.

7. The use of a superior impregnated wire with an improved non-raveling tendency greatly simplifies the working of wires into the slots.

In addition, the strength of terminals was improved by using a special prestressed terminal (Figure 3).

Steps 5 and 6 above are shown in photographs taken at the initial winding of the prototype HRL stator assembly (Figures 4 and 5). The initial "hold-back" of the first six coils prior to final coil insertion is illustrated, and a closeup of the slot portion is shown. This enlargement of the "coil throw" area shows the slot-cell-protection ring in the lower edge of the photo and the unruffled coil geometry before and after slot entry.

The motor-winding drawings were revised to include all the minor deviations from the drawing incorporated in the first -1 stators. Adjustments were required to facilitate wire and insulation installation in slot-liner and phase-separator dimensions, end-turn size, neutral buss connections and placement, extra insulation in the slot-to-wedge top stick, and perimeter size (Figures 6 and 7).

The winding and insulating techniques employed in the present fabrication method (3-week cycle per stator assembly, not including encapsulation) were developed through study of a trial unit and rejection of the first prototype winding attempt.

Additional work was done in the areas of ceramic impregnation, encapsulation, and diamond grinding. To completely define the process of impregnating and encapsulating the HRL and primary-loop NaK motors with inorganic cements, insulation-system models were subjected to a series of trials.

Two wound stators (HTM-5 and HTM-6) available from the previous SNAP-8 two-loop-system program were installed in housings and were conditioned as follows: Unit HTM-5 was impregnated with a low-viscosity slurry of calcium aluminate cement and was encapsulated with Norton LM-1625 cement. Immediately thereafter, the winding end turns were filled with the cement and vibration was applied to the housing in an attempt to fill all voids in the winding-end-turn areas (Figure 8). Unit HTM-6 was impregnated with a low-viscosity calcium aluminate slurry and was then encapsulated with LM-1625 cement. The encapsulant was pressed in place at a pressure of 500 psi.

Following curing of the ceramic cements, the trial stators were sectioned and inspected. Sections of each unit are shown in Figure 9 along with Unit HTM-4, which had previously been encapsulated with LM-1625 cement under a pressure of 500 psi. The inspection results were as follows:

Stator	Findings
HTM-4	Some voids were found in the winding end turns, but the ceramic encapsulant appeared very dense and was without cracks.
HTM-5	The end turns were well filled with encapsulant, but the encapsulant was cracked in several areas.
HTM-6	A satisfactory fill of ceramic was achieved throughout the end-turn area, and no cracks were observed in the encapsulant.

Because it was thought that a 500-psi pressure might distort the stator end winding and cause electrical failure at a later time, an additional housing with a blank stator in place was potted using a combination of vibration and 250-psi placement pressure (Figure 10). This sample was in excellent condition following both curing and thermal aging for 168 hours at 1000°F. The process pressure for all future units will consequently be reduced to 250 psi.

A final processing test was run to check all steps in the impregnation and encapsulation procedure. A trial HRL-motor stator was installed in a dummy housing; was heat-conditioned to remove organics; was impregnated, encapsulated, and cured; and was finally conditioned at 1000°F for 406 hours. The unit was then cycled ten times from room temperature to 1000°F.

Figure 11 shows the unit following the test. No cracks were observed in the ceramic, and the material appeared to be dense and well bonded. Based on the above work, a process specification (Ref. 2) was prepared in final form and was issued.

Concurrent with work on the latter unit, a second housing was filled with a blank stator, was encapsulated and cured, and was sent to the NaK-motor-assembling vendor for bore-sizing and can-expansion trials. The vendor tried to machine the core cement with a single point diamond, but this approach was found to be unsatisfactory. Dry diamond grinding was then tried and was successful. Ref. 2 will be revised to incorporate this change. Figures 12 and 13 show an HRL motor in the as-cast condition, and Figures 14 and 15 show the same motor after bore grinding.

E. SUPPORT WORK FOR RADIATION-EFFECTS PROGRAM

The fabrication of electrical-insulating-material specimens for evaluation in the SNAP-8 radiation-effects program was essentially completed. Four insulation-system models (statorettes) were fabricated. Two use ML-polymer organic-insulation systems (Figure 16), and the others use inorganic-insulation systems identical to those now employed in the HRL and primary-loop motors (Figure 17). Also fabricated were magnet-wire-twist specimens and organic-encapsulant cubes with embedded electrodes. Some of the latter specimens are shown in Figure 18.

Altogether, 72 encapsulant cubes were fabricated, of which 75% were organic types and the rest were inorganic. Other materials used in the program include various tapes, sheets, laminates, ceramic through-type terminals, sleevings, cloths, polyphenyl ether (mix-4P3E and mix-5P4E), and flexible lead wires. Following fabrication, the statorettes, encapsulant cubes, and wire-twist specimens were measured for key electrical properties to provide Aerojet with reference data.

These materials and system models have been irradiated, but post-irradiation testing had not been completed by the end of this report period.

Detailed material lists and testing procedures are presented in Ref. 3.

F. CERAMIC TERMINALS

Ceramic through-type terminals designed by Aerojet for the main leads of the HRL and primary-loop motors have been received and helium-leak-tested. All passed the leak test satisfactorily. A torque value of 15 in.-lb has been established for assembling the terminal to the motor-housing mounts. The new terminal (Figure 3) is expected to be more reliable than standard commercial types, because it transmits applied mechanical forces to the motor housing directly and does not rely on the strength of the ceramic-metal joint to resist structural strain.

Efforts were resumed on a test that was previously developed to determine the vacuum reliability of ceramic terminals at elevated temperature. Figure 19 shows a trial assembly in which a ceramic terminal is welded to a metal mount, which in turn is welded to a metal tube. The metal tube is joined to a glass tube by a glass-to-metal seal. The procedure planned to evaluate a ceramic terminal at elevated temperature is as follows:

1. A vacuum is developed on the assembly, and all joints are helium-leak-checked.

2. While the vacuum is established inside the tube, the glass tube is flame-sealed.

3. The assembly is placed in a furnace, with the terminal inside and the glass tube extended through the modified furnace door (Figure 20).

4. Prior to and throughout the test at elevated temperature, the pressure inside the glass tube is monitored by means of an electric field applied by a Tesla coil (Figure 20). A vacuum of about 5×10^{-4} torr will exhibit a very light blue color, 1×10^{-3} torr is indicated by a light purple color, 5×10^{-2} torr is indicated by a dark purple, and atmospheric pressure is indicated by absence of color.

The testing of four ceramic-metal terminals (Alite B-50-13 type), sealed at 1×10^{-4} torr, was completed after 500 hours of exposure at 1000°F. The terminals showed no degradation electrically and no apparent change due to leakage. The Alite Division of the U.S. Stoneware Company has been qualified as a second source for ceramic-metal terminals.

The Advac terminals (Type A 2501) for the HRL and primary-loop NaK motors were received and were successfully applied to the first HRL motor. No leakage or welding problems were encountered.

G. COMPATIBILITY OF COPPER AND MIX-4P3E POLYPHENYL ETHER

The electrical windings of the mercury-pump motor, the alternator, and the L/C-pump motor are exposed to mix-4P3E vapor and/or liquid. Because no insulation system is completely free of pinholes, it is important to determine the conditions of chemical interaction between copper and the fluid. The capsules and their contents after heat treatment for 144 hours at 300°F are illustrated in Figure 21, and the preliminary results are summarized in Table 12 (which defines the sample numbers used in Figure 21).

The conclusion reached from visual inspection (analysis has not yet been completed) is that copper and mix-4P3E do not interact when the mix is pure and no oxygen or oxygen source is present.

Side results of this test series are conclusions (1) that magnesium oxide will clarify and purify mix-4P3E to the point of lowering its acid number even after contamination, and (2) that mix-4P3E does not darken as readily after treatment with magnesium oxide. It is believed that the magnesium oxide acts as a surfactant and either absorbs or reacts with the phenol groups produced by oil degradation.

H. SUPPORT WORK FOR CONTROLS GROUP - IMPREGNATION OF INDUCTORS

Three magnetic inductors were wound and impregnated with Furane Epocast 17-A to determine possible degradation effects on their magnetic properties. The material was selected because of its thermal stability (see Table 1), low viscosity, and compatibility with ML-insulated wire. After impregnation and cure, the three units were temperature-cycled and tested for variation from the as-wound condition; the variation was found to be minor (approximately 2 cps).

REFERENCES

1. Insulated Motor (Inorganic), Winding of, Procedure for, Aerojet-General Process Specification AGC-10284, 5 December 1963.

2. Insulated Motor (Inorganic) Impregnating and Potting, Procedure for, Aerojet-General Process Specification AGC-10285, 3 December 1963.

3. SNAP-8 Irradiation Test Program for Aerojet-General Corporation, Proposal No. ETP-402 from Georgia Nuclear Laboratories, Lockheed Georgia Company, a subsidiary of Lockheed Aircraft Corporation, July 1963.

TABLE 1

ORGANIC-RESIN WEIGHT LOSS, FIRST RUN
(168 HOURS AT 392°F IN AIR)

Material	Type	% Loss*
3M Scotchcast 292	Epoxy impregnant	6.97
3M Scotchcast 241	Epoxy encapsulant	3.26
3M Scotchcast 235		6.60
Epoxylite 813-9		0.96
Epoxylite 8793		0.45
Epoxylite 8794		0.61
Epoxylite 2154		3.41
Furane Epocast 17-B	Epoxy encapsulant	0.94
Furane Epocast 17-A	Epoxy impregnant	0.31
Furane Epocast 3	Epoxy impregnant	0.69
Hysol 7-4252	Epoxy encapsulant	2.70
GE novolak epoxy	Epoxy encapsulant	0.30
GE Bisphenyl A epoxy	Epoxy encapsulant	0.57
Dow Corning Sylgard 182	Silicone-elastomer encapsulant	2.01
Dow Corning Sylgard 183	Silicone-elastomer encapsulant	1.60
Dow Corning Sylgard 7521	Silicone impregnating resin	3.79

*Because all percentages are referred to the organic base, differences in filler contents are not reflected in the loss values.

TABLE 2

ORGANIC-RESIN WEIGHT LOSS AT 392°F, SECOND RUN

Material	Type	% Loss* After Exposure Times Shown			
		168 Hours	336 Hours	504 Hours	1196 Hours
3M Scotchcast 292	Epoxy impregnant	5.33	6.20	6.93	8.43
3M Scotchcast 241	Epoxy encapsulant	2.19	2.44	2.70	3.67
3M Scotchcast 235		4.63	5.00	5.32	6.06
Epoxylite 813-9		0.25	0.36	0.51	0.99
Epoxylite 8793		0.28	0.44	0.63	1.09
Epoxylite 8794		0.31	0.52	0.74	1.39
Epoxylite 2154		4.84	6.24	7.65	10.82
Furane Epocast 17-B	Epoxy encapsulant	0.58	0.78	0.97	1.44
Furane Epocast 17-A	Epoxy impregnant	0.35	0.51	0.74	1.50
Furane Epocast 3	Epoxy impregnant	0.51	0.76	1.09	2.32
Hysol 7-4252	Epoxy encapsulant	2.11	2.79	3.30	4.60
GE novolak epoxy	Epoxy encapsulant	0.22	0.32	0.41	0.66
GE Bisphenyl A epoxy	Epoxy encapsulant	0.62	0.80	1.00	1.51
Dow Corning Sylgard 182	Silicone-elastomer encapsulant	1.42	1.75	2.03	3.38
Dow Corning Sylgard 183	Silicone-elastomer encapsulant	1.49	1.78	1.98	2.49
Dow Corning Sylgard 7521	Silicone impregnating resin	1.74	2.24	2.65	3.93

*Because all percentages are referred to the organic base, differences in filler contents are not reflected in the loss values.

TABLE 3

STATORETTE INSULATION SYSTEMS*

Units	Slot Liners and Phase Insulation	Varnish
HML-1 and HML-2	Pyre-ML polyimide-coated glass fabric, Du Pont Quality Code 6508	Pyre-ML polyimide varnish, Du Pont Type RK-692
ML/997-1 and ML/997-2	Macallen 806P mica-paper composite	Dow Corning 997 silicone varnish
ML-3 and ML-5	Pyre-ML polyimide-coated glass fabric, Du Pont Quality Code 6508	Pyre-ML polyimide varnish, Du Pont Type RK-692
ML-4 and ML-6	Pyre-ML coated glass fabric, Type 6508	Westinghouse Doryl Type B-109-4 (diphenyl oxide)

*Throughout, magnet-wire is Anaconda heavy ML polyimide film over copper.

TABLE 4

STATORETTE HML-1 - D-C INSULATION RESISTANCE
WINDING TO GROUND (AGED IN MIX-5P4E AT 392°F)*

Hours of Aging	Resistance ohms**	Hours of Aging	Resistance ohms**
240	3.0×10^9	4517	8.6×10^9
480	2.8	4661	8.6
792	3.3	5069	7.0
1152	3.4	5285	8.8
1508	5.0	5466	6.73
1751	5.3	5562	6.7
1991	5.8	5852	7.75
2231	6.4	6023	7.0
2687	6.6	6167	6.8
3137	7.7	6983	6.5
3461	6.5	7487	6.5
3629	6.4	8085	8.0
3965	7.7	8253	8.0×10^9
4133	8.6	9307	1.0×10^{10}
4301	8.6×10^9	9709	8.9×10^9

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - ML.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 5

STATORETTE HML-2 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN AIR AT 392°F)*

Hours of Aging	Resistance ohms**	Hours of Aging	Resistance ohms**
240	5.0×10^{11}	4517	5.0×10^{11}
480		4661	5.0
792		5069	5.0
1152		5285	1.25
1508		5466	1.25×10^{11}
1751		5562	7.0×10^{9}
1991		5852	4.9×10^{10}
2231		6023	
2678		6167	
3137		6983	
3461		7487	
3629		8085	
3965		8253	
4133		9307	4.9×10^{10}
4301	5.0×10^{11}	9709	6.7×10^{11}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - ML.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 6

STATORETTE ML/997-1 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN AIR AT 392°F)*

Hours of Aging	Resistance ohms**	Hours of Aging	Resistance ohms**
408	5.0×10^{11}	4317	5.0×10^{11}
648		4485	
816		4701	
1056		4845	
1320		5253	5.0×10^{11}
1608		5469	1.25×10^{11}
1800		5673	5.1×10^{9}
2020		5724	∞
2279		5841	
2423		6159	
2687		6206	
2879		6350	
3089		7166	
3353		7670	
3645		8268	
3813		8436	∞
4149	5.0×10^{11}	9490	5.0×10^{11}
		9892	5.8×10^{11}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - mica-paper composite; varnish - Dow Corning 997.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 7

STATORETTE ML/997-2 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN MIX-5P4E AT 392°F)*

Hours of Aging	Resistance ohms**	Hours of Aging	Resistance ohms**
576	5.6×10^{9}	4485	1.7×10^{10}
648	5.6	4701	1.8
1056	5.9	4845	1.8
1320	6.8	5253	1.9
1608	8.1	5469	2.1
1800	9.1	5673	1.3×10^{10}
2020	9.5	5724	2.17×10^{9}
2279	7.7×10^{9}	5841	2.9
2423	1.05×10^{10}	6159	8.0
2687	1.23	6206	8.2
2879	1.21	6350	7.78
3089	1.4	7166	7.6
3353	1.73	7670	8.3×10^{9}
3645	1.23	8268	1.1×10^{10}
3813	1.23	8436	1.1×10^{10}
4149	1.73	9490	1.2×10^{10}
4317	1.7×10^{10}	9892	1.2×10^{10}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - mica-paper composite; varnish - Dow Corning 997.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 8

STATORETTE ML-3 - D-C INSULATION RESISTANCE
WINDING TO GROUND (AGED IN MIX-4P3E AT 392°F)*

Hours of Aging	Resistance ohms**
45	6.6×10^{7}
137	1.27×10^{8}
213	1.72
305	2.2
499	2.13
623	2.0
814	8.4×10^{8}
1630	5.3×10^{9}
2134	9.1×10^{9}
2732	9.0×10^{10}
2900	9.3×10^{11}
3954	3.5×10^{11}
4356	3.7×10^{11}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - ML.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 9

STATORETTE ML-4 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN MIX-4P3E AT 392°F)*

Hours of Aging	Resistance ohms**
45	4.4×10^{7}
137	1.0×10^{8}
213	1.2
305	1.3
499	1.37
623	1.18
814	1.28
1630	1.3
2134	1.7
2732	3.4
2900	5.7×10^{8}
3954	2.0×10^{9}
4356	1.7×10^{10}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - Westinghouse Doryl.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 10

STATORETTE ML-5 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN AIR AT 392°F)*

Hours of Aging	Resistance ohms**
45	∞
137	
213	
305	
499	
623	
814	
1630	
2134	
2732	
2900	
3954	∞
4356	7.0×10^{11}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - ML.

**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are averages of readings for three coil groups.

TABLE 11

STATORETTE ML-6 - D-C INSULATION RESISTANCE WINDING TO GROUND (AGED IN AIR AT 392°F)*

Hours of Aging	Resistance, ohms**
45	1.69×10^{10}
137	5.25×10^{10}
213	1.19×10^{11}
305	5.32×10^{11}
499	8.0×10^{10}
623	1.75×10^{11} to 1.0×10^{12}
814	3.5×10^{11} to 1.0×10^{12}
1630	6.5×10^{11}
2134	6.5×10^{11}
2732	∞
2900	∞
3954	5.0×10^{11}
4356	8.7×10^{11}

*Insulation system: magnet wire - heavy ML over copper; slot liners and phase insulation - ML-coated fiber-glass cloth; varnish - Westinghouse Doryl.

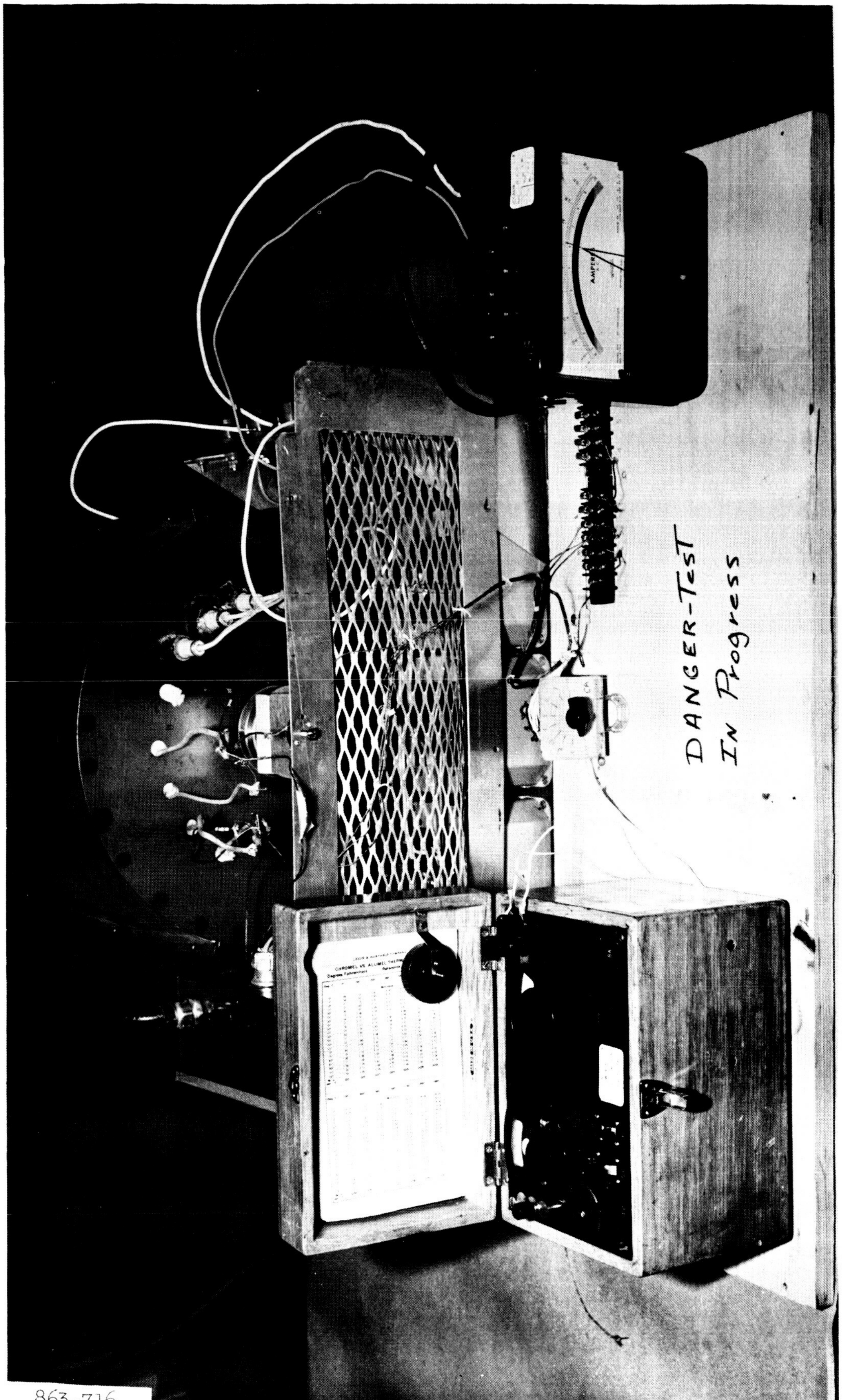
**Measured with General Radio 544B megohm bridge; 500 v, dc; 1-min reading. Values given are average of readings for two coil groups.

TABLE 12

COMPATIBILITY OF MIX-4P3E AND COPPER

Sample No.	Condition of Mix-4P3E (Dow Lot 12-2P)	Additives	Cover Gas	Results: Mix-4P3E	Results: Copper
1	Distilled	Copper	Nitrogen	No change	No change
2	Distilled	Copper	Oxygen	Very dark	Surface attack
3	As received	Copper	Nitrogen	Slight darkening	No change
4	As received	Copper	Oxygen	Very dark	Attack at liquid line
5	As received	Copper + 1% water	Nitrogen	Very dark, turbid	Surface attack
6	Distilled	None	Nitrogen	No change	No change
7	Distilled	None	Oxygen	Slight darkening	
8	As received	None	Nitrogen	Slight darkening	
9	As received	None	Oxygen	Very dark	
10	Distilled	Copper + MgO	Nitrogen	Clear, no color*	
11	As received	Copper + MgO	Nitrogen	Clear, no color	
12	Distilled	MgO	Nitrogen	Clear, no color	
13	As received	MgO	Nitrogen	Clear, no color	No change

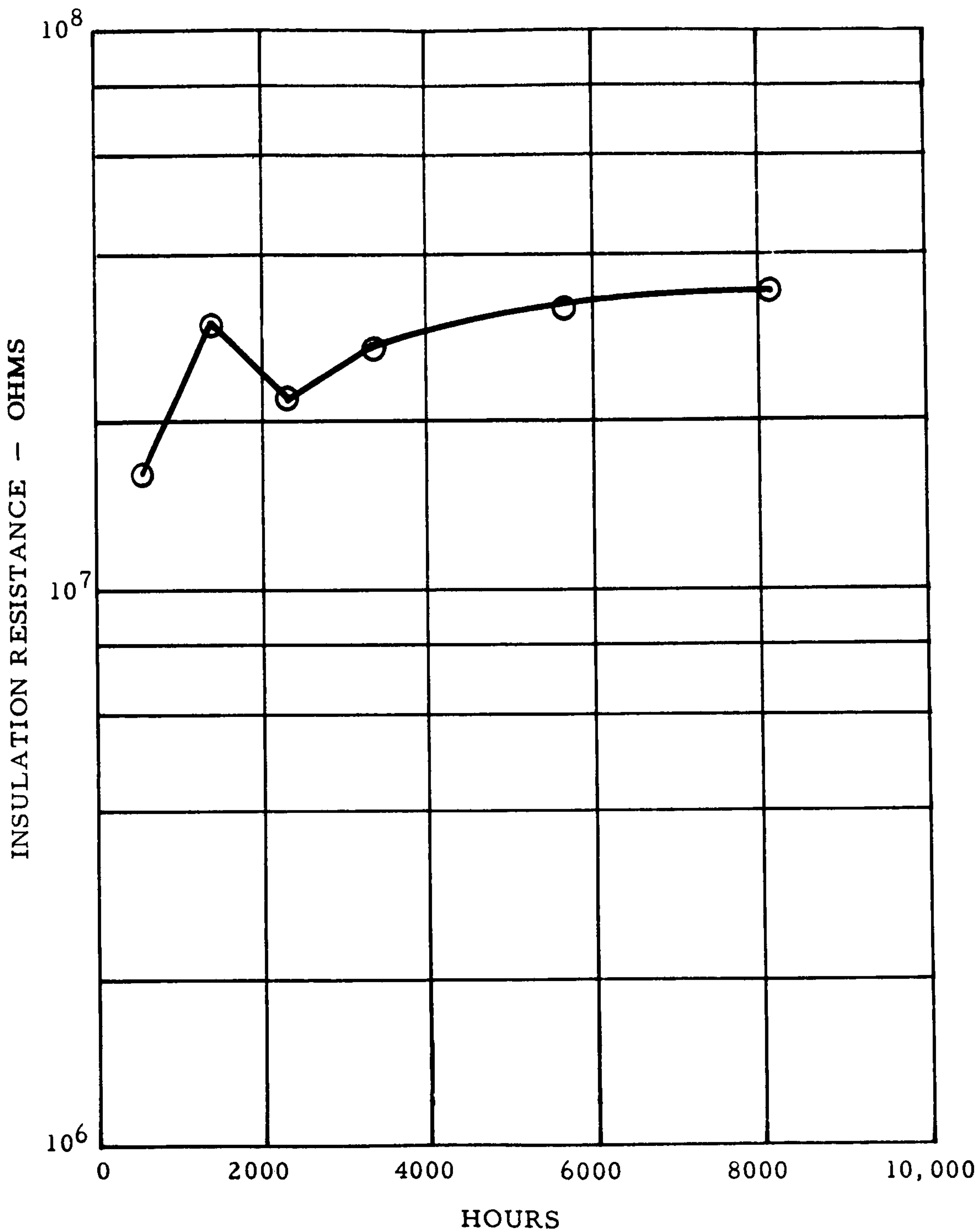
*Tube walls cloudy due to magnesium oxide coating.



863-716

Inorganic-Insulated Motor Undergoing Test at Elevated Temperature

Figure 1



Analysis of Insulation-Resistance Readings of HTM-2 at 450°F
(Insulation-Resistance Design Requirement = 10^6 ohms)

Figure 2

NOTES: 1. REMOVE ALL BURRS AND SHARP EDGES

2. INTERPRET DRAWING PER STANDARDS PRESCRIBED IN MIL-D-7

3. TIG WELD PER AGC-STD-2795.

4. PART NO PP1202 PLASTI-PARTS MONROVIA, CALIF.

5. VENDOR ITEM SEE SPECIFICATION CONTROL DRAWING FOR PROCURE

6. HELIUM LEAK TEST PER MIL-STD-271 NO LEAK SHALL BE DETECTE INSTRUMENT CAPABLE OF MEASURING A FLOW RATE OF 1×10^{-8} F (1x10^{-7} CC/SEC). ALL LEAKS SHALL BE IDENTIFIED FOR REWORK.

7. TORQUE NUTS TO LOAD SEAL AND WASHER FOR STUD LEAK CHE TO NOTE NO. 6. TORQUE VALUE AND SEAL RESULTS TO BE R

8. MARK PER ASD 5215 N WITH PART NO. 093404-1 AND ASSIGNED A

9. AFTER FINAL ASSY AND WELDING, TERMINAL MUST WITHSTAND DI OF 1500 VAC FOR 1 MINUTE AT 22°C.

10. TACK WELD NUTS AFTER APPLYING TORQUE PER 7.

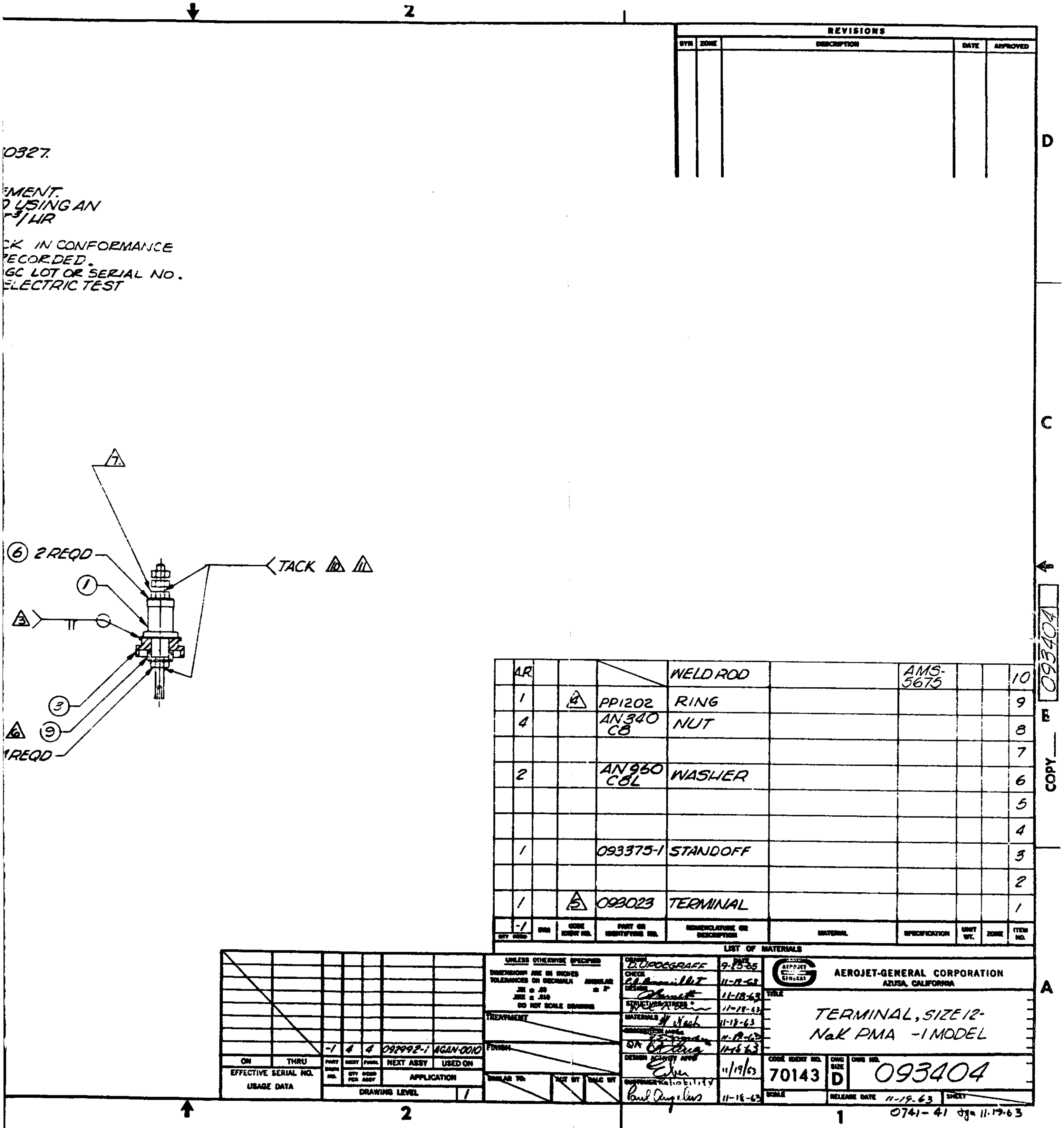
11. TIG WELD PER AGC STD 2795 USING FILLER ROD PER AMS 5675.

12. PACKAGE PER MIL-P-116 METHOD III.

6

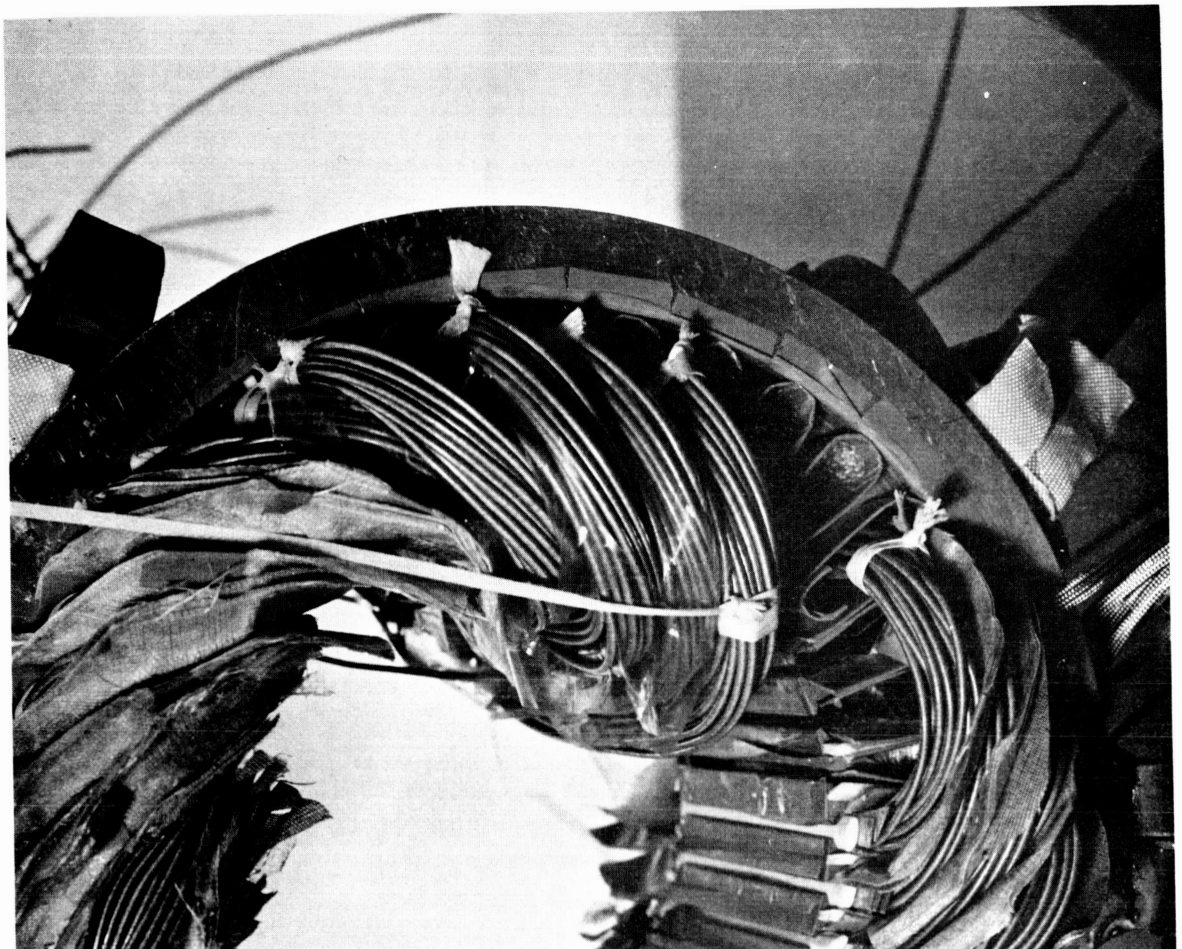
8 4

2



Size 12 Terminal for NaK PMA, -1 Model

Figure 3

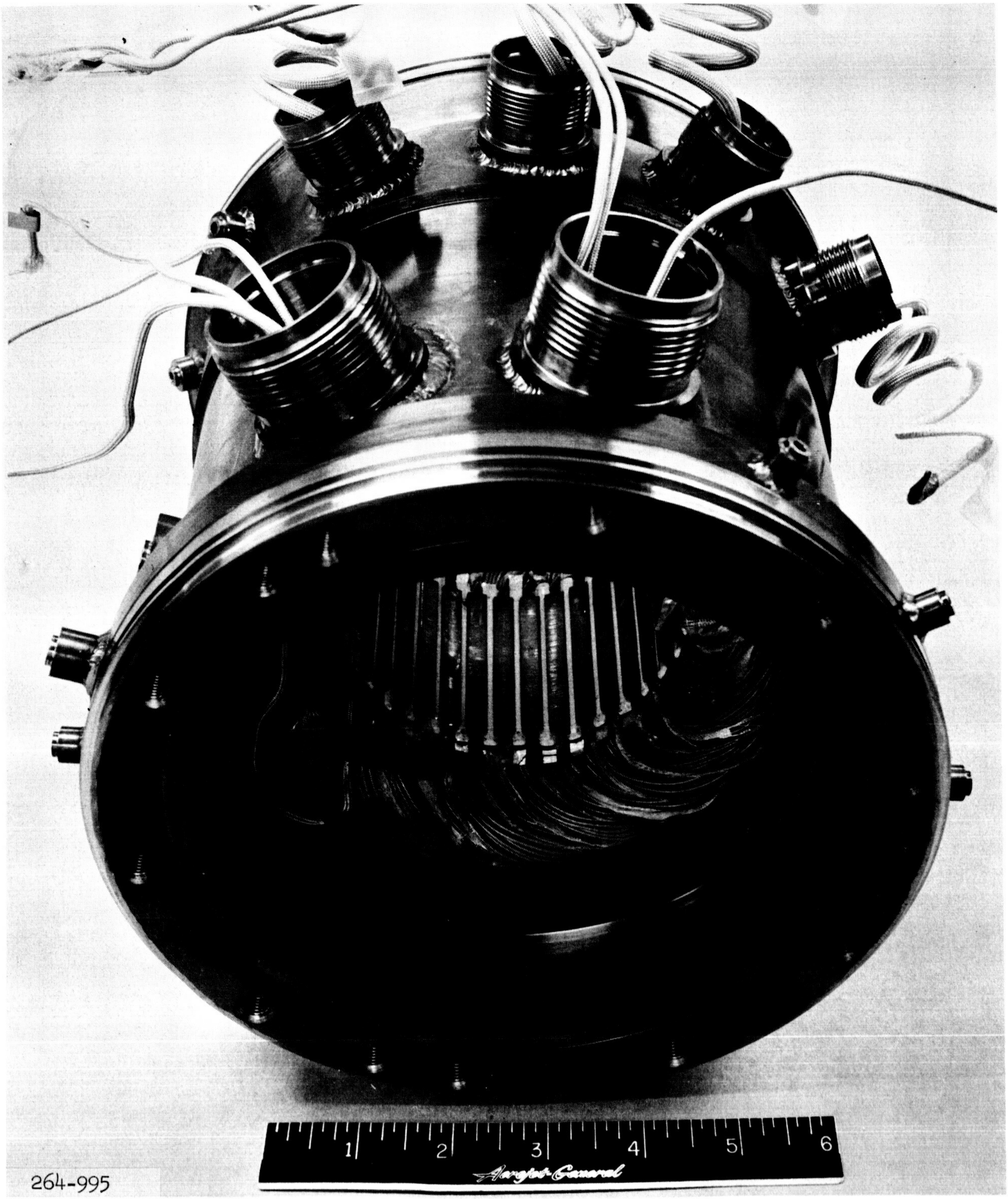


HRL Stator - Second Inorganic Winding Opposite Connection End

Figure 4

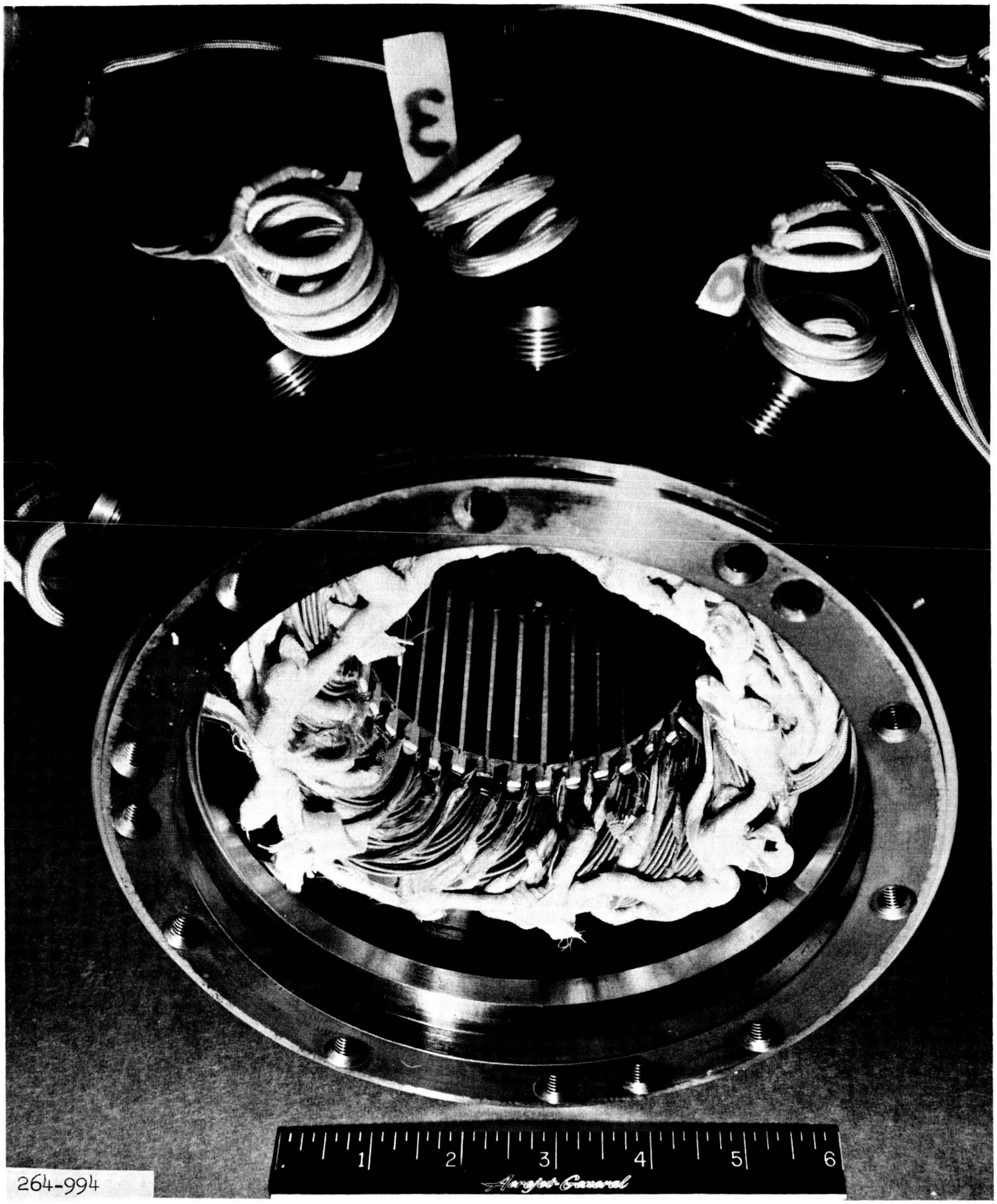
HRL Stator - Second Inorganic Winding, Connection End

Figure 5



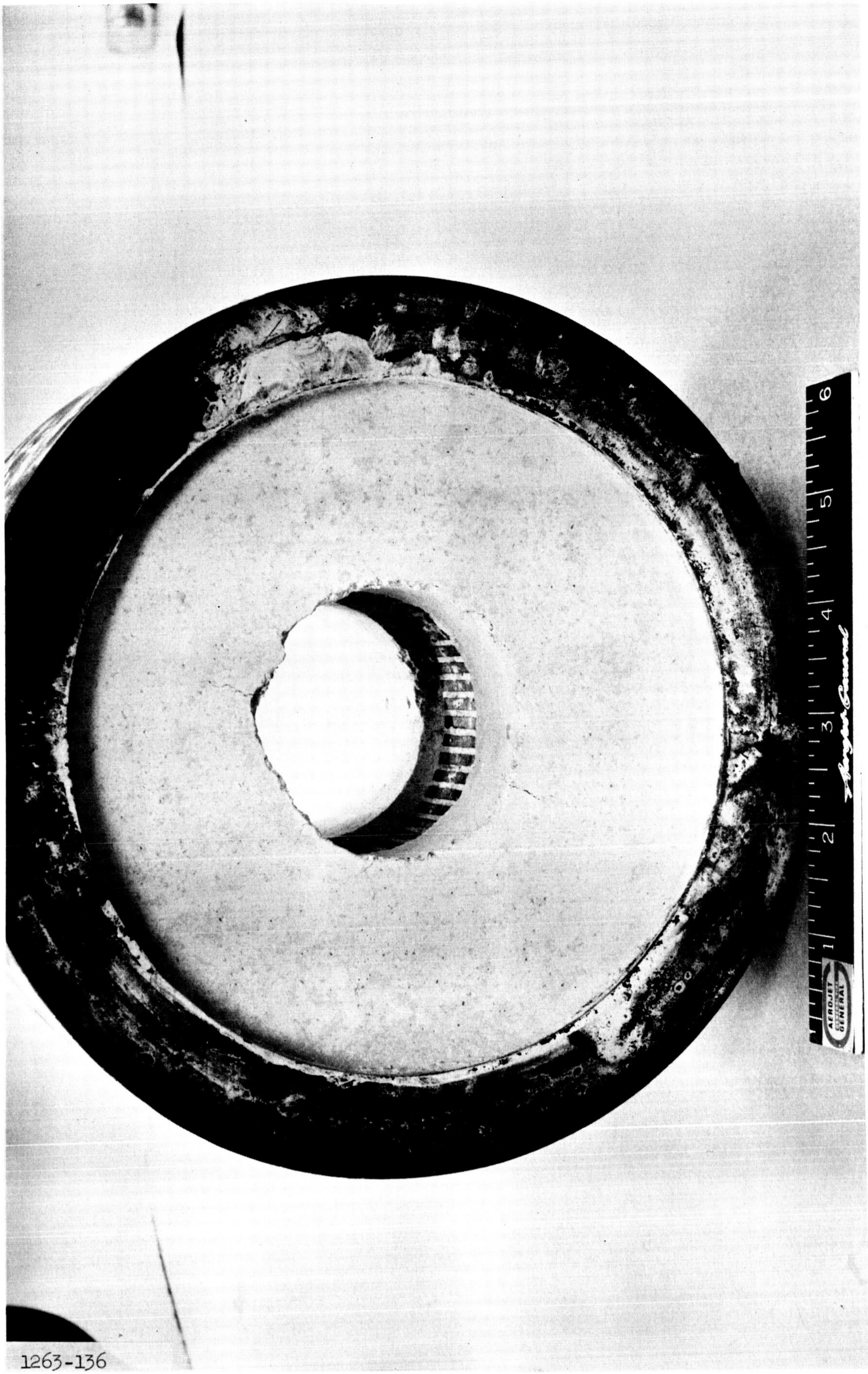
First HRL Stator in Housing - Opposite Connection End

Figure 6



First HRL Stator in Housing - Connection End

Figure 7



HTM-5 After Final Cure and Aging for 168 Hours at 1000°F

Figure 8

Encapsulation Trials - HTM Series Using IM-1625 Cement

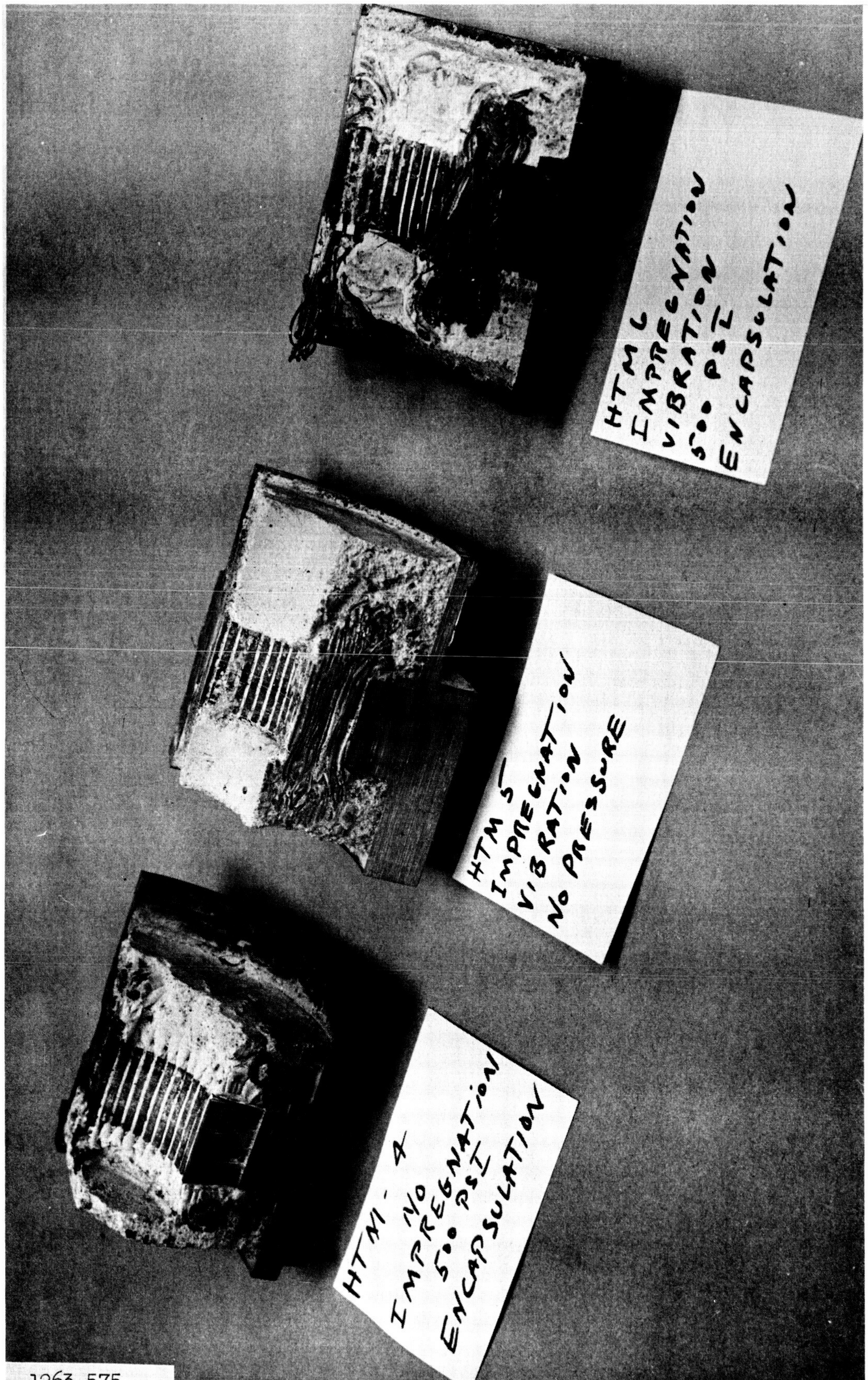
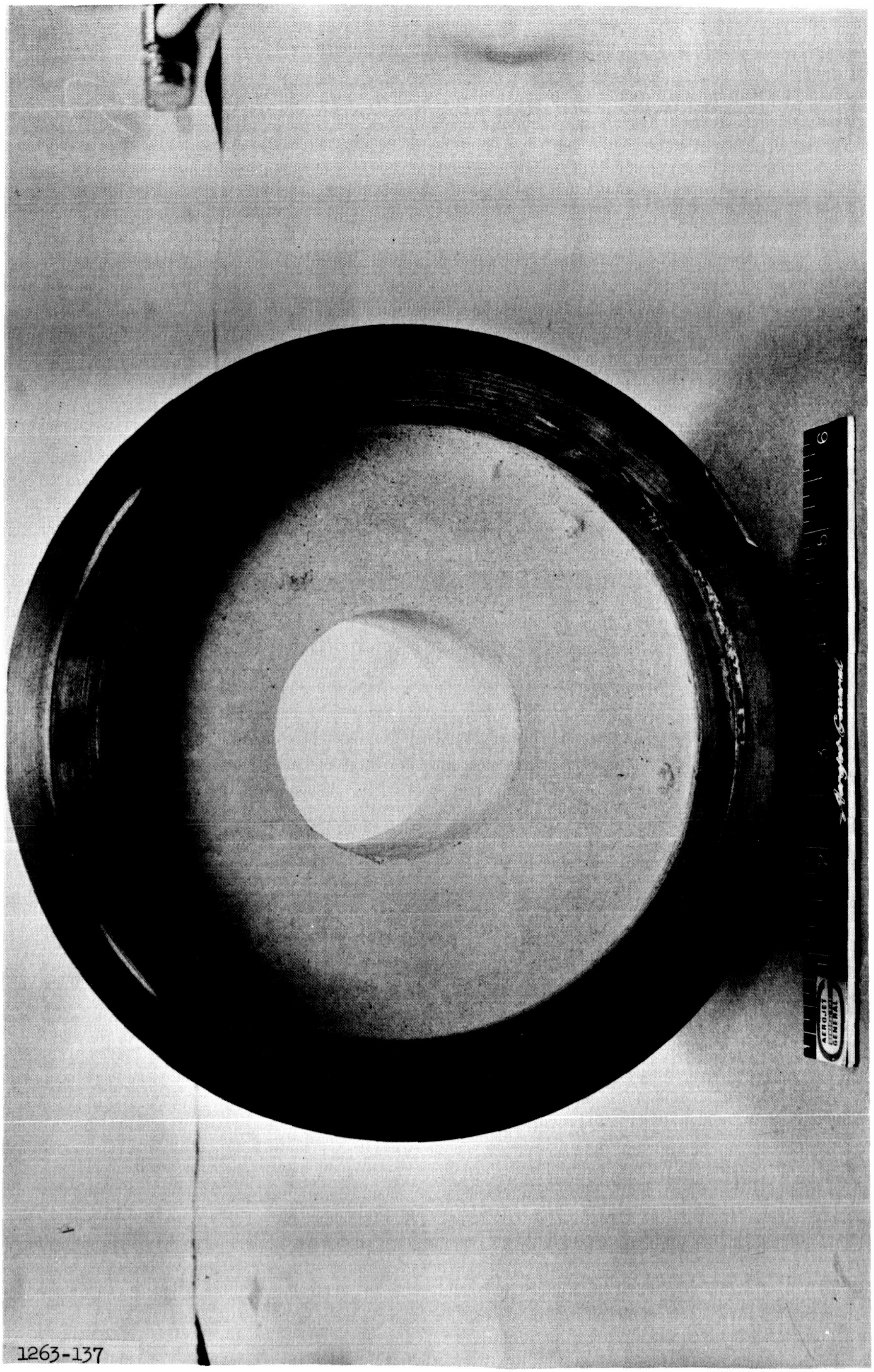
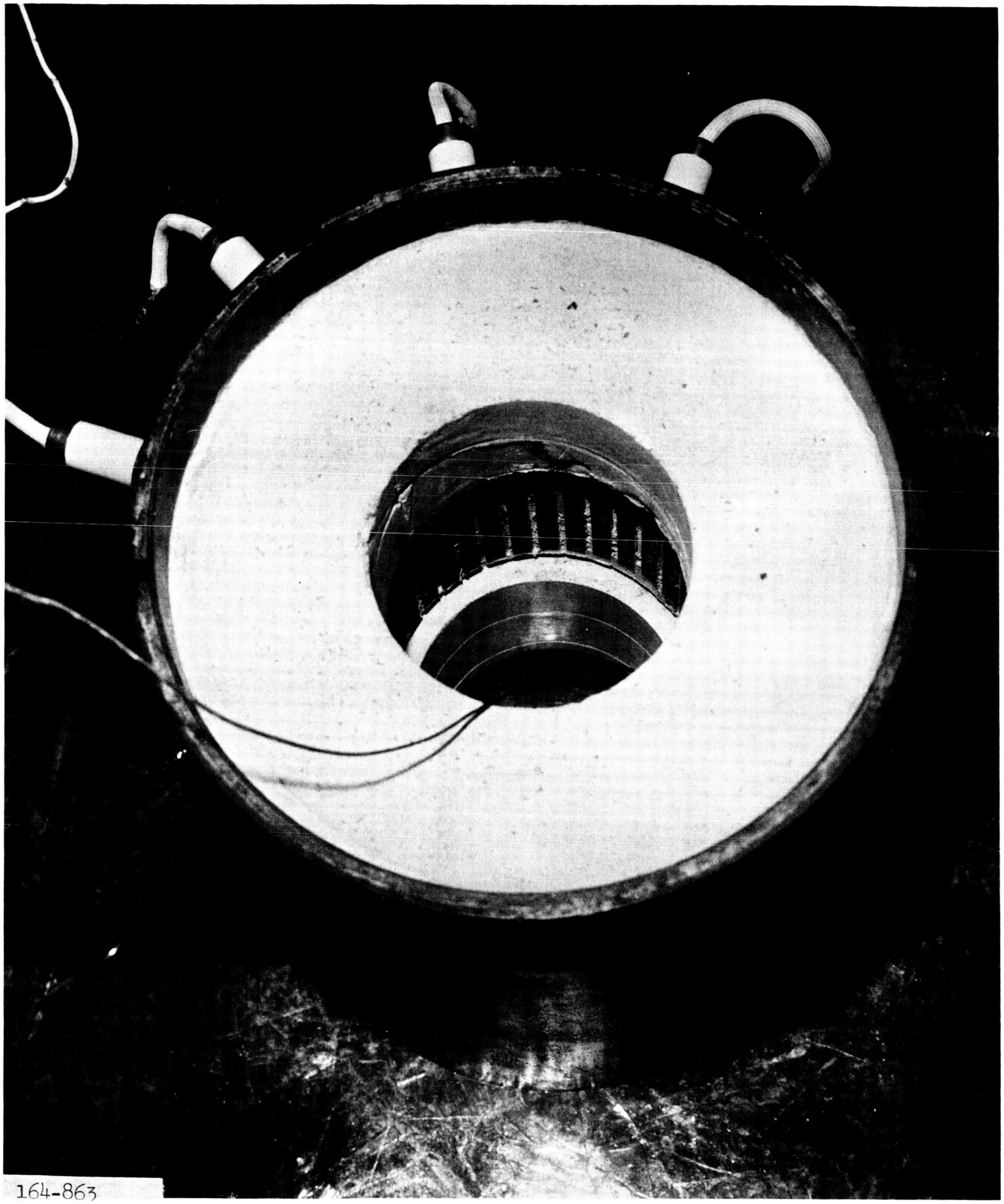


Figure 9



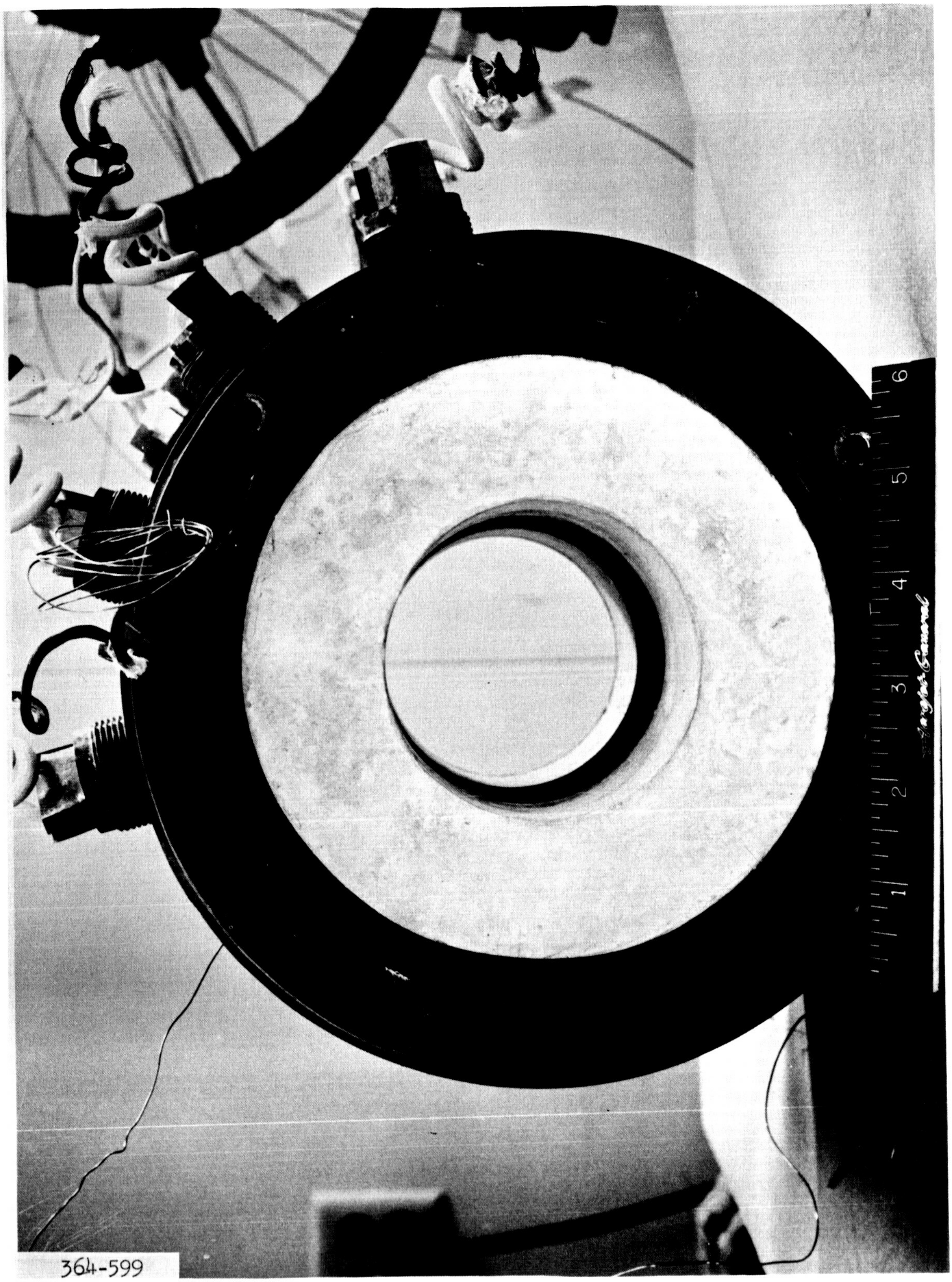
Encapsulation Trials - IM-1625 Pressed at 250 psi After Final Cure

Figure 10



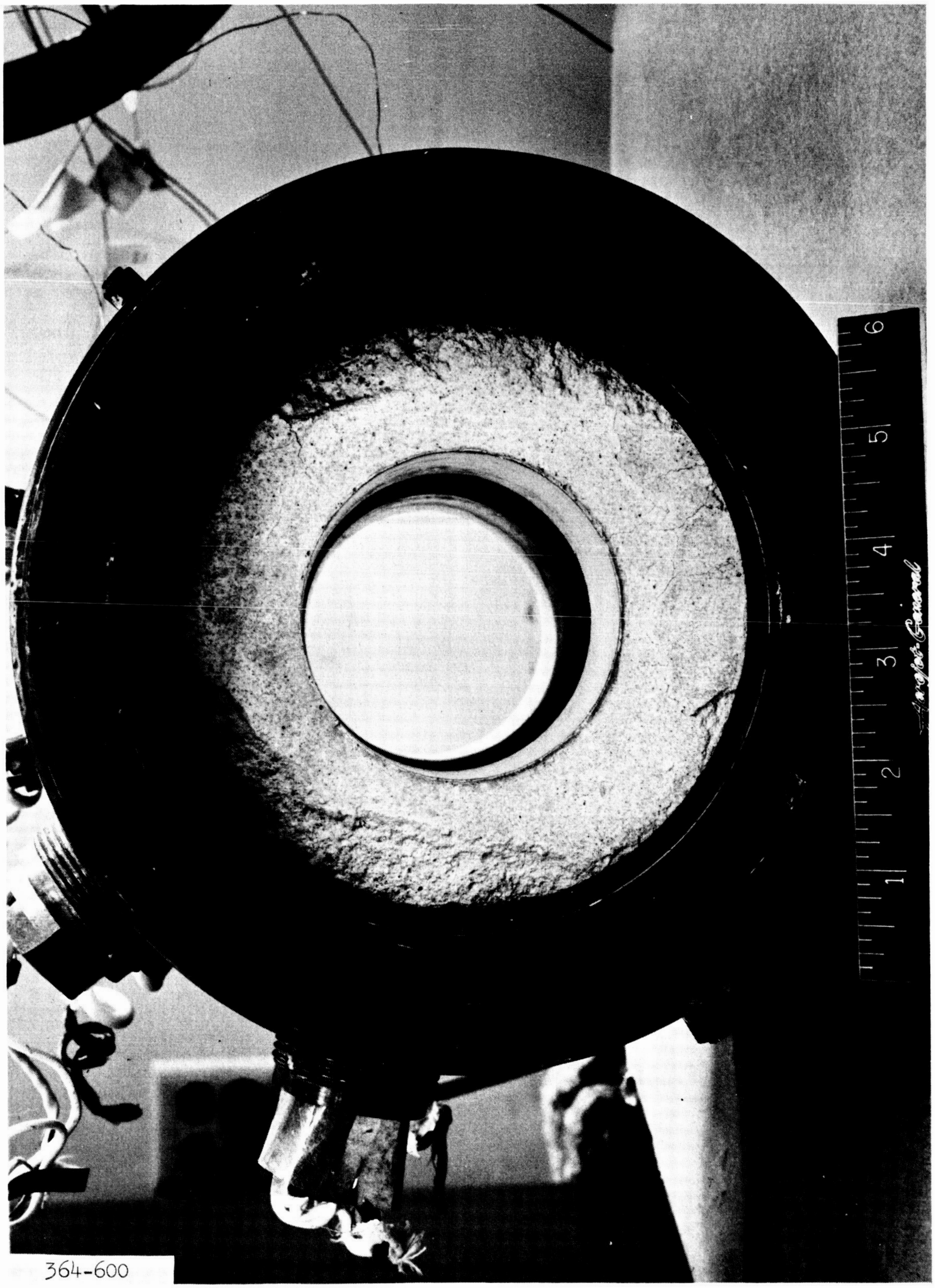
Trial HRL Encapsulated Stator After 406 Hours at 1000°F

Figure 11



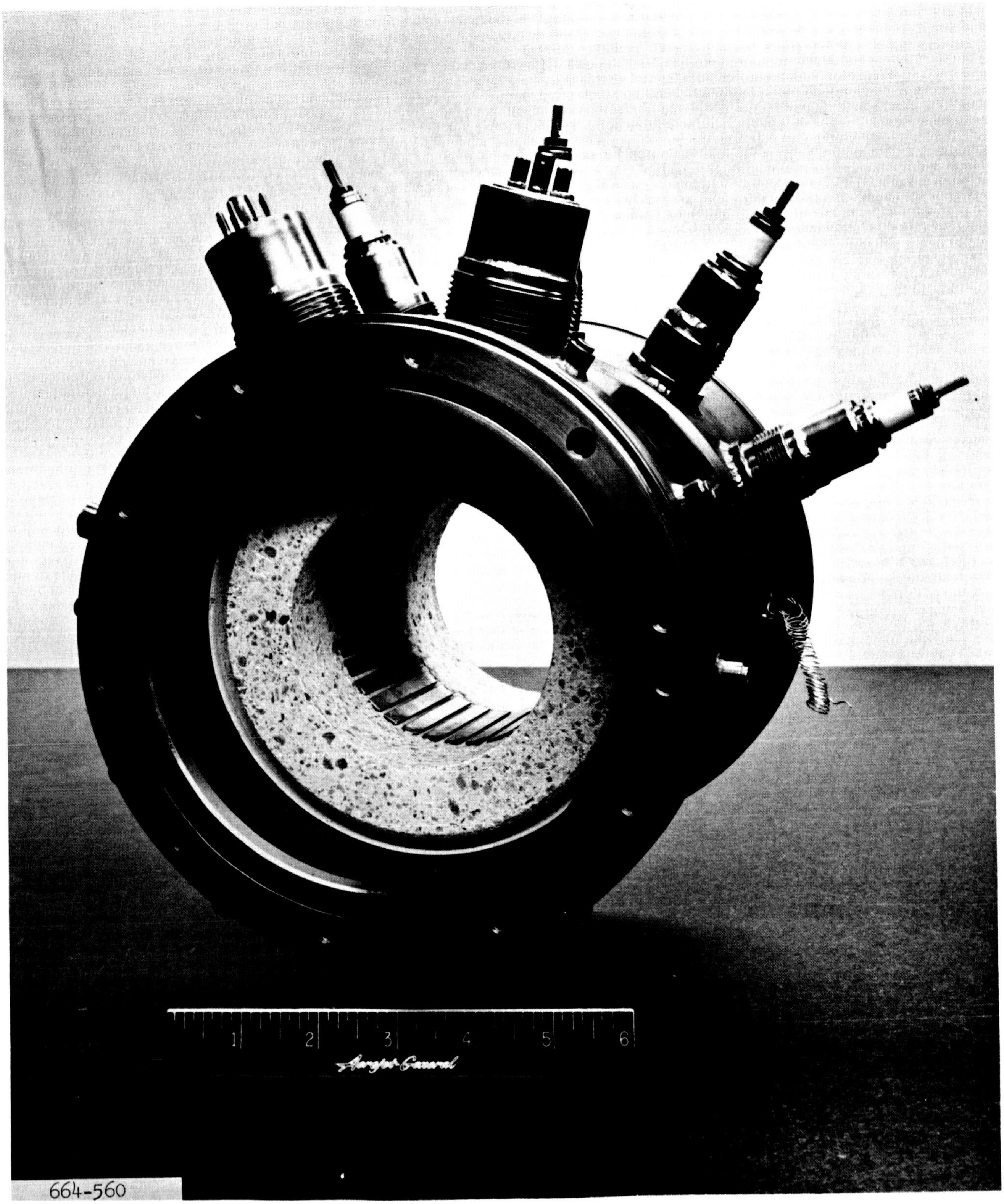
HRL Motor After Encapsulant Cure - Connection End

Figure 12



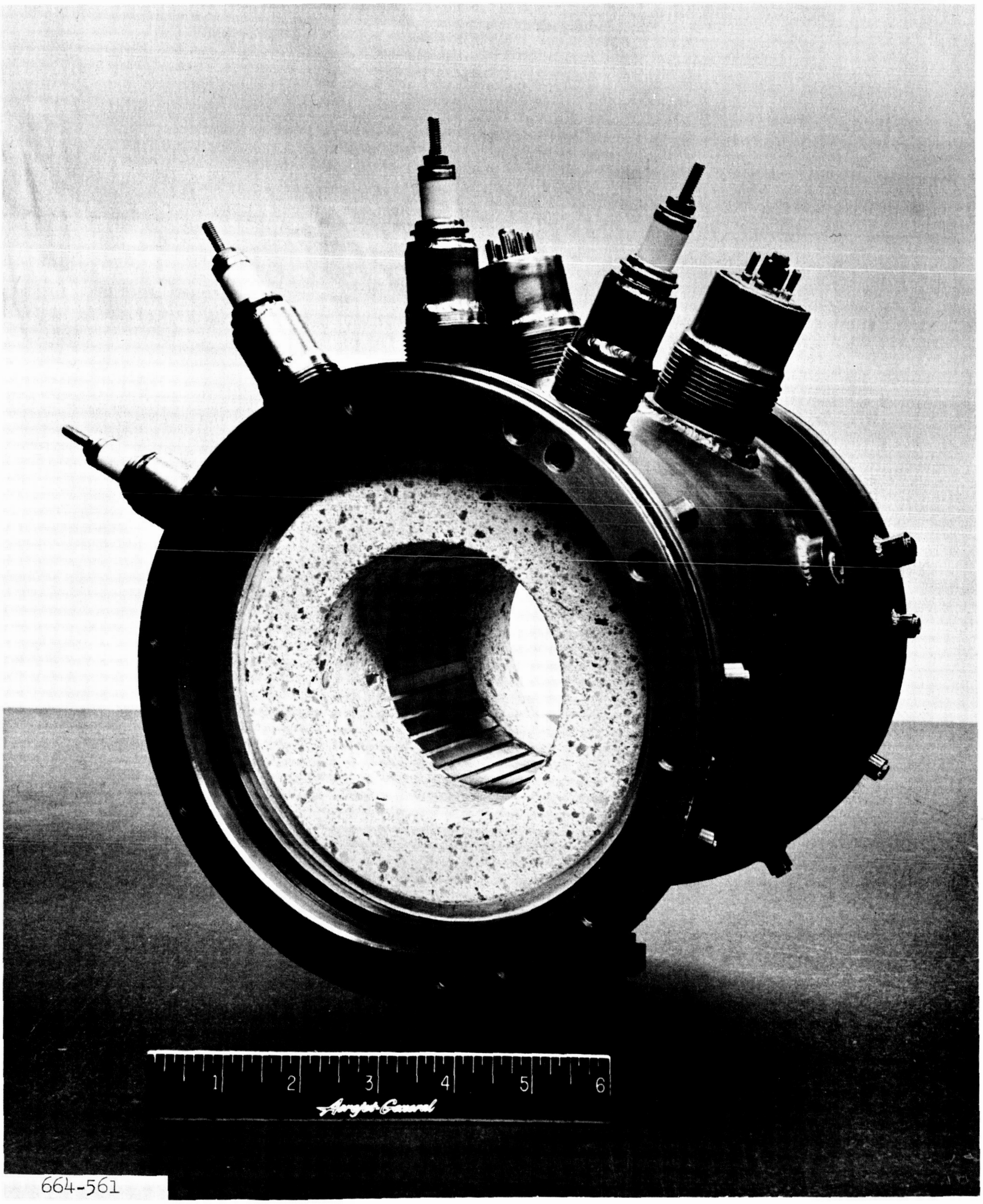
HRL Motor After Encapsulant Cure - Opposite Connection End

Figure 13



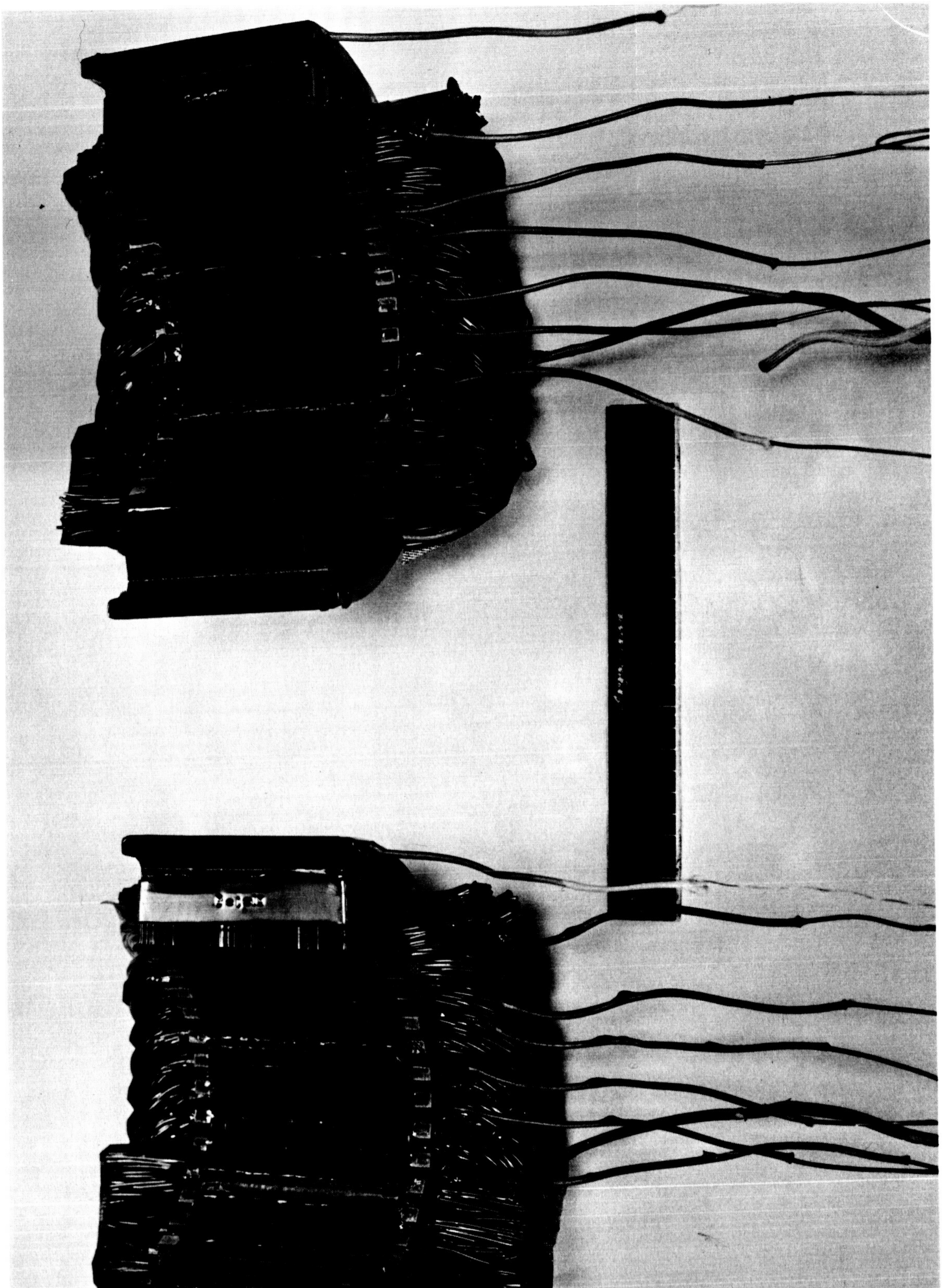
HRL-1, Opposite Connection End After Grinding of Ceramic Encapsulant

Figure 14



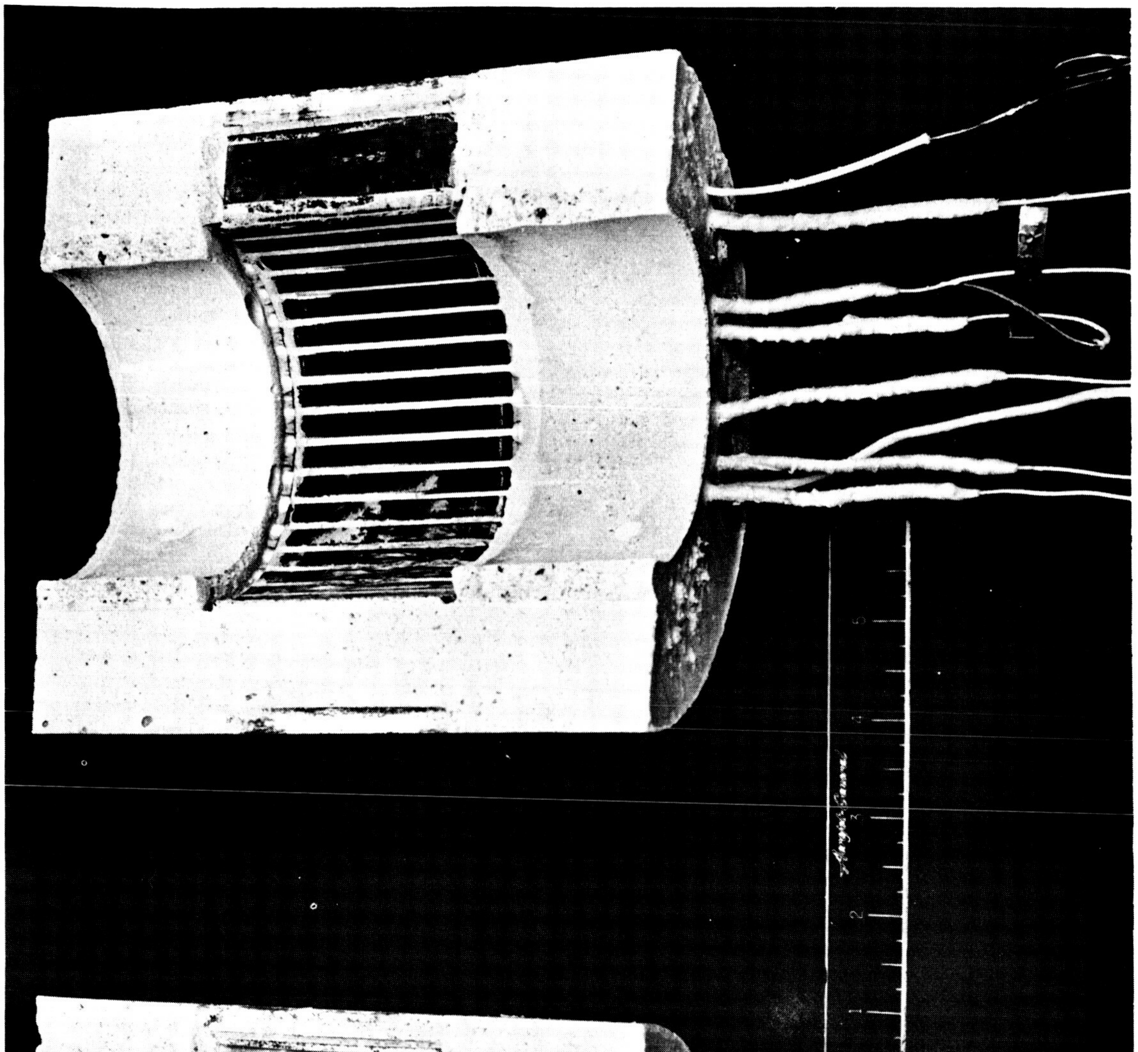
HRL-1, Connection End After Grinding of Ceramic Encapsulant

Figure 15



Organic Statorettes for Radiation Effects Program

Figure 16



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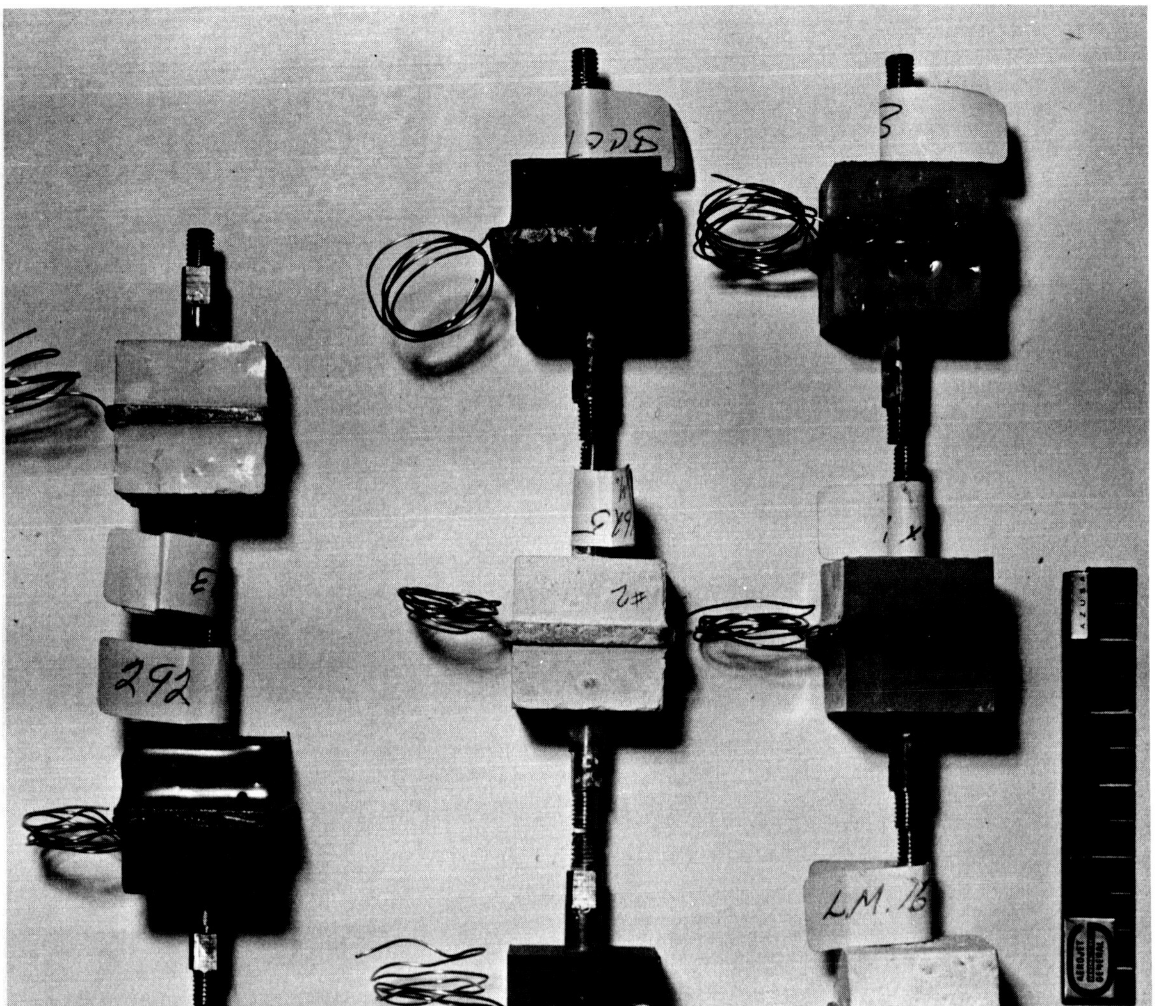
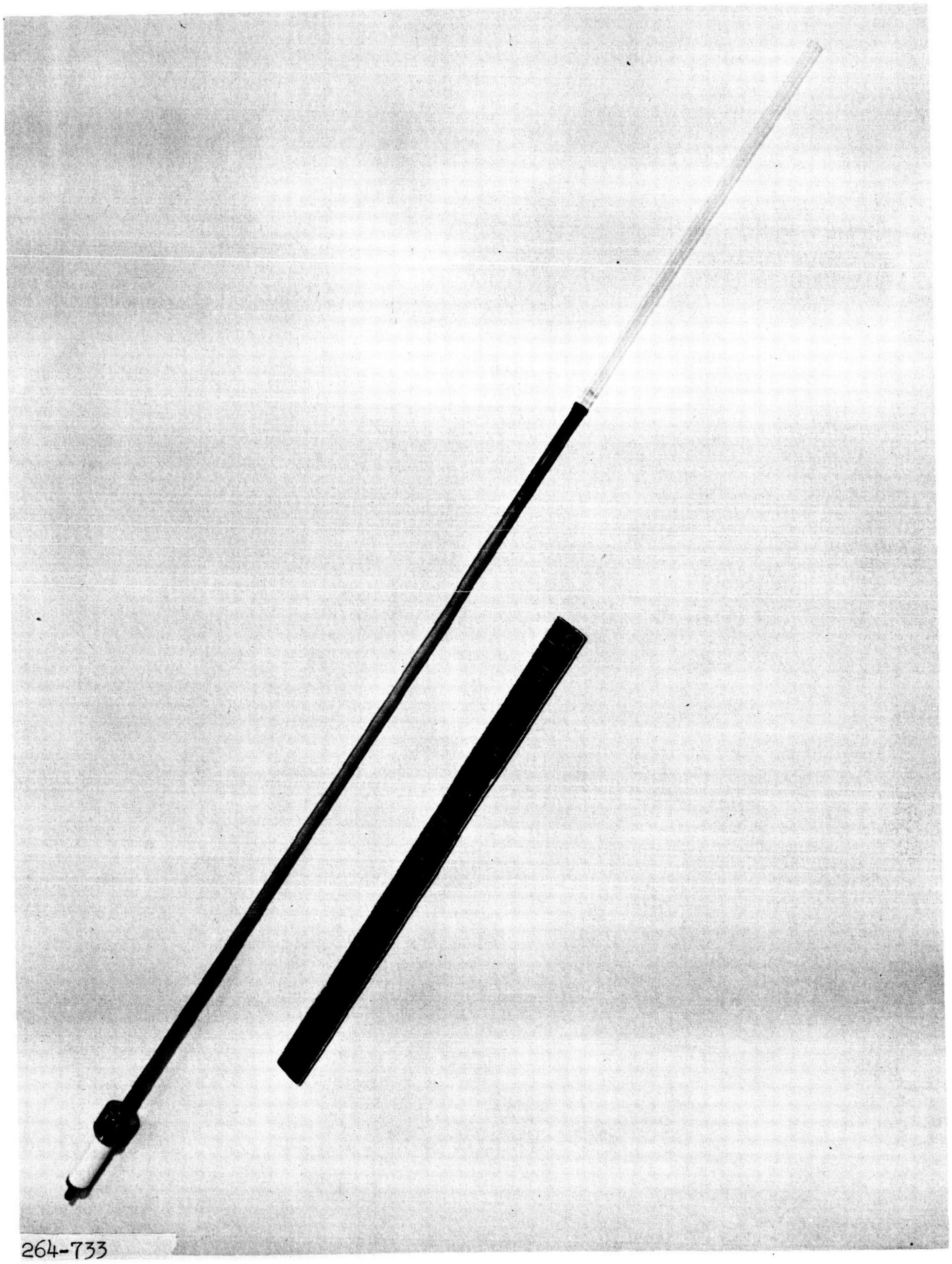
Inorganic Statorettes for Radiation Effects Program

Figure 17



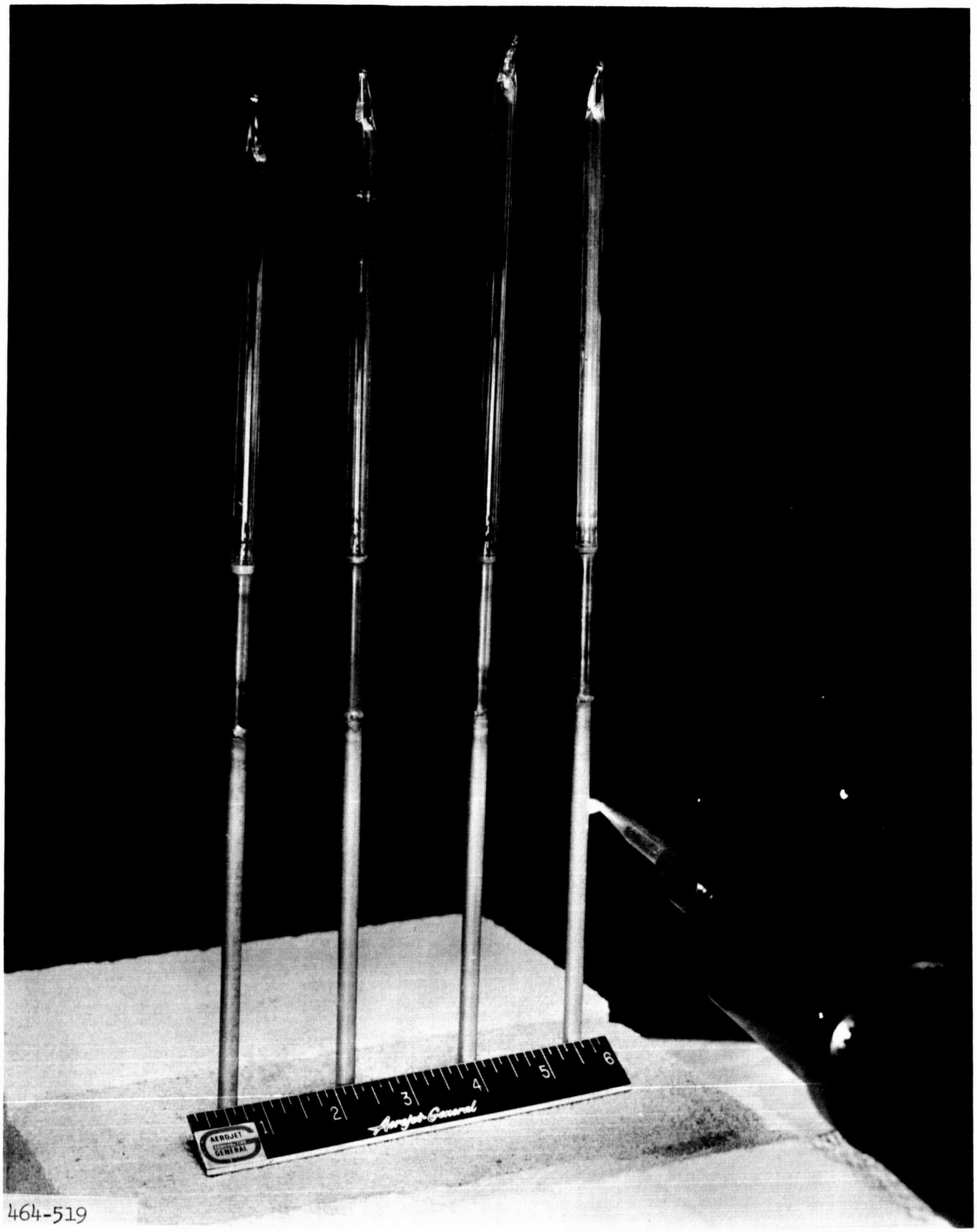
Organic-Encapsulant Samples Ready for Electrical Evaluation

Figure 18



Terminal Ready for Long-Term Vacuum Aging at 1000°F

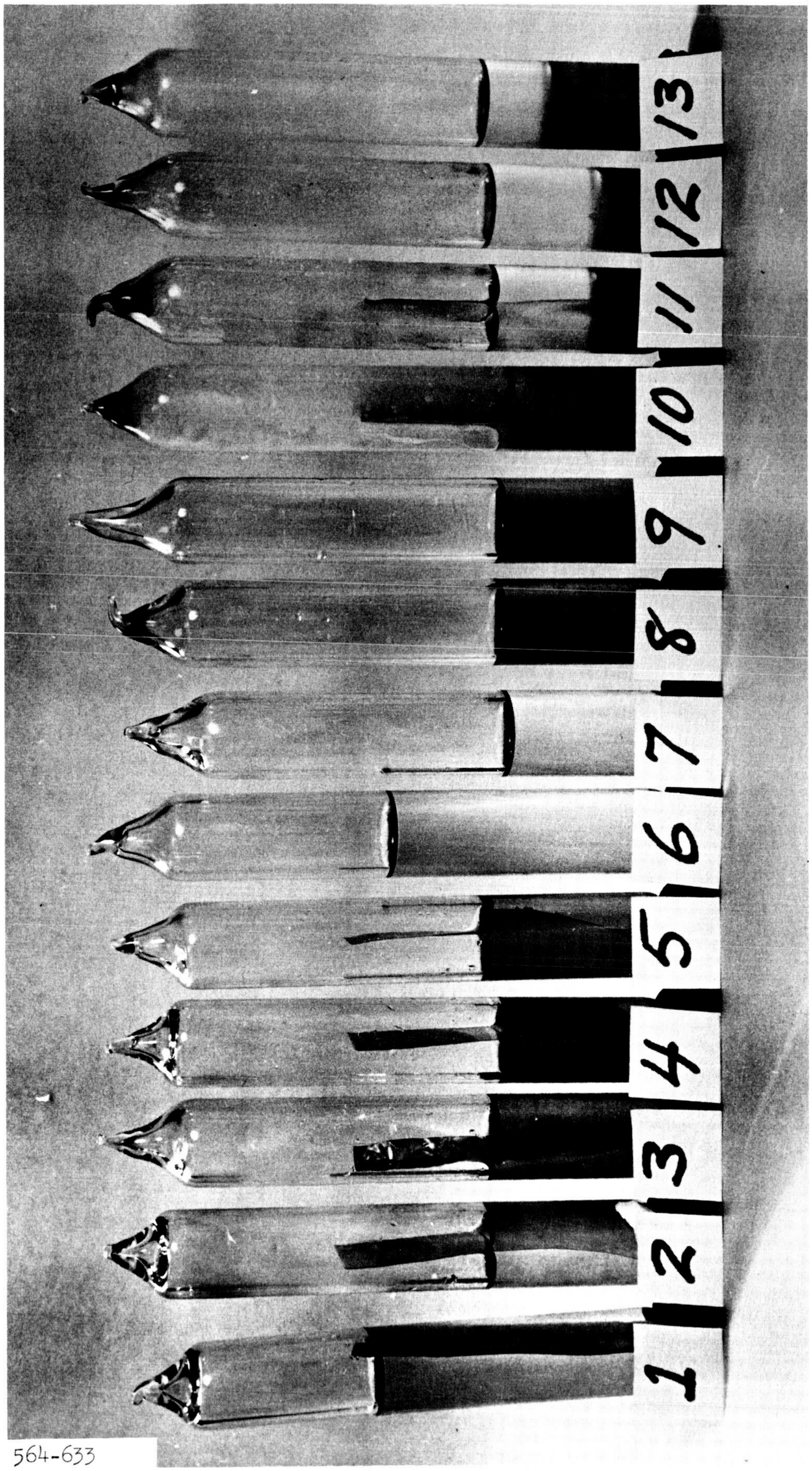
Figure 19



464-519

Terminal Test at 1000°F and 1 x 10^{-4} Torr Vacuum, Measured by Illumination of Sealed Glass Tube by Tesla Coil

Figure 20



Sealed-Capsule Compatibility Test, Mix-4P3E/Copper
After 144 Hours at 300°F

Figure 21

Report No. 2880, Vol. I

NASA CONTRACTOR REPORT

SNAP-8 MATERIALS REPORT FOR JANUARY-JUNE 1964

VOL. I - ELECTRICAL INSULATION DEVELOPMENT

Aerojet-General Corporation

ABSTRACT

The purposes of the SNAP-8 Electrical Insulation Development Program are (1) to select, test, and evaluate insulating materials and systems applicable to SNAP-8 components, (2) to fabricate inorganic insulation systems for the NaK pump-motor assemblies, and (3) to coordinate Aerojet-General and subcontractor activities in electrical insulation. During this report period, previously developed insulation systems were applied to SNAP-8 hardware and the results were studied. The first inorganic-insulated stator was completed, and Aerojet-designed terminal insulators were received.

Report No. 2880

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